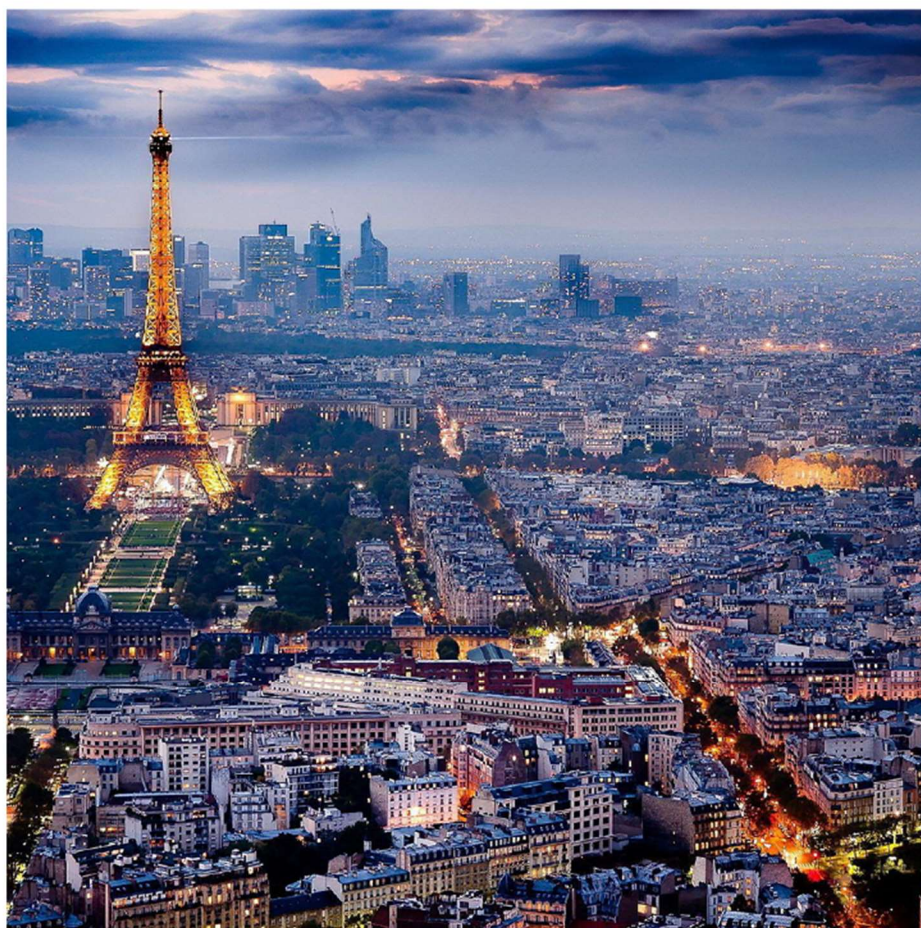


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Psychological Sciences

Adolescents' self-identity and self-concept: psychological bases of the problem

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Keywords: adolescents, self-concept, mental health, identity, teenagers

Self-concept plays a vital role in a person's life. It contributes to defining self-identity and successful adaptation, forms and maintains a person's value structure, and ensures personal integrity and the stability of external behavioral manifestations. Furthermore, self-concept can determine a person's direction and is the source of self-esteem and aspirations, which, combined with real achievements, influence motivation and self-satisfaction. Self-concept also encompasses those personal qualities that support the establishment of identity, its manifestation and self-development, and self-realization in the profession, determining one's attitude toward academic activities and interactions with the professional and social environment.

In scientific literature, self-concept is described as, on the one hand, a relatively stable structure, and on the other, one that undergoes dynamics throughout life. This duality is associated with the presence of a subjective evaluative component in its formation. This duality allows for effective psychocorrective interventions on specific substructures, altering self-perception and behavioral manifestations. The self-concept of a person undergoes a long developmental phase, beginning at birth, even in infancy, and determines a person's attitude toward themselves as an individual. Disruption to the dynamics of the developing self-concept of future specialists contributes to the development of an identity within its structure that is inadequate to changing conditions. The phenomenon of self-concept in modern science is associated with the works of such scholars as W. James, C. Rogers, R. Burns, E. Erickson, J. Mead, C. Cooley, G. Allport, A. A. Bodalev, L. S. Vygotsky, J. Steines, and others. The "self-concept" as a plurality of personality, combining several "selves," was first considered by the American psychologist William James in 1890. His emergence is associated with a dual understanding of the nature of human consciousness. On the one hand, W. James defines consciousness as the knowing or pure Ego; this aspect of consciousness presupposes the possibility of knowing the surrounding reality.

Personality encompasses everything a person can call their own, including not only their self-concept in terms of physical and psychological characteristics, but also all the material objects and achievements they can identify as such.

Personality analysis itself is carried out in relation to:

- 1) its constituent elements;
- 2) the feelings and emotions they evoke (self-esteem);
- 3) the actions they evoke (self-care and self-preservation)."

Thus, W. James identifies cognitive, emotional-evaluative, and behavioral components in the structure of self-concept. In turn, he divided the constituent elements (i.e., the cognitive component) into physical, spiritual, and social personality. The cognitive aspect of a future specialist's self-concept reflects personality traits related to academic activity and interaction with the professional and social environment. Physical personality represents a set of various material objects that we appropriate and with

which we establish an emotional connection. According to William James, physical personality primarily includes one's own body and what we clothe it with, that is, clothing. James understands spiritual personality as the totality of various states experienced by a person, including their moral, religious, and philosophical attitudes. Its core is the sense of activity characteristic of some of these states. Social personality is the totality of all the social roles a person uses in various life situations when interacting with other individuals and how those around them perceive and evaluate these roles. The final formation of classical ideas about the "self-concept" occurred in the 1950s within the mainstream of humanistic psychology after the publication of the scientific works of Carl Rogers. In his concept, the key concepts are the "real self" and the "ideal self." Later, Charles Cooley and John Mead supplemented his model with another component – the "mirror self."

During adolescence, the issue of identity becomes acute again. Because confluence with reference groups was active in the preceding years, by the onset of puberty, although peer pressure is still significant, the individual strives to define their own identity. This stage is similar to the stage of negativism at age two. The emergence of dissonance in self-perception is exacerbated by the ambivalent attitudes of elders. On the one hand, they are situationally perceived as an adult, subject to certain demands and responsibilities; on the other hand, their rights are still limited; parents strive to control their child's life and do not always allow them to make independent choices. All this leads to the adolescent's desire to separate and clearly define their own self. During this period, the "mirror self" takes on particular significance. How the adolescent is perceived by others signals to them the effectiveness of their identity. If self-identification is not properly developed during adolescence and the individual is forced to rely on external influences, they become dependent on external evaluations and, as a result, more susceptible to external influence, increasing their own suggestibility. A lack of this kind of separation during adolescence can lead to officers interacting with criminal elements internalizing their values and attitudes, thereby increasing the risk of the officer committing a crime or misdemeanor. Therefore, this category of officers requires periodic psychological counseling and interaction with trusted supervisors.

During adolescence, the ideal self develops. As a result of familiarity with the social order, a desire for a certain social status and conformity to chosen idols develops. Due to youthful maximalism, the ideal self during adolescence may differ from its perception as an adult; it is still unstable and dynamic. Over time, a more stable position regarding the ideal self develops, but this can also change with experience. The prosociality of the ideal self depends, among other things, on the reference group and significantly influences goal setting and a person's direction. As noted above, the discrepancy between the images of the ideal and the real self leads to dissonance within the personality and entails a lack of integrity. Intrapersonal conflict of this kind can lead to frustration, maladjustment, and decreased mental health, but this depends on the degree of discrepancy. A positive self-perception and an adequate level of aspirations, combined with a minor discrepancy between the ideal and actual self-images, are a necessary element of self-control, a motivational focus on achieving one's ideals, a sign of psychological maturity, and are reflected in social and professional spheres of life. Thus, each stage of maturation is accompanied by the formation of certain elements of the self-concept, reflecting on the individual's self-perception and directly influencing various areas of life, including professional life.

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PECS- picture exchange communication system with autism spectrum disorders

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Keywords: autism, picture exchange communication system, education, social skills, learning

Picture exchange communication system (PECS), based on the principles of applied behavior analysis and based on normal language and communication development stages, it is an alternative illustrated communication system developed for individuals with ASD (Bondy & Frost, 2001; Charlop-Christy, Carpenter, Le, LeBlanc, & Kenneth, 2002; Kircaali-İftar, 2007). PECS is used to teach individuals to communicate in a social context. Initially, using PECS, individuals are taught to give a picture (picture card) to a communication partner to retrieve the desired object (Wong, 2013b). Thus, individuals are enabled to initiate communication to achieve a goal. Studies carried out that PECS leads to an increase in imitation, communication and speaking skills and a decrease in problem behaviors (Bondy and Frost, 2001; Charlop-Christy et al., 2002). The PECS teaching process begins with teaching how to communicate using picture cards.

It consists of six stages that continue until the construction of complex sentences with pictures to fulfill different functions of communication (Bondy and Frost, 2001; Wong, 2013b). The first phase is the phase in which students are taught how to communicate without using words. In this phase, individuals are taught to turn to or approach the communication partner, initiate communication by handing the picture card to the communication partner, and achieve the desired result through communication initiation behavior.

The second phase is about distance and determination. This is the phase in which it is acquired. In this phase, individuals are taught to continue initiating communication persistently and decisively, even when the distance between them and the communication partner increases or some obstacles arise.

The third stage is the stage in which people learn to distinguish symbols in order to make messages special. In this phase, individuals are asked to pick the picture card belonging to the object they want among more than one picture card. They are taught to give it to their communication partner and eventually reach the desired object.

The fourth stage is the stage in which the ability to form sentences is acquired. In this stage, individuals are given requests such as "I want" or they are taught to form sentences by combining cards containing opinion expressions such as "I see" and "I hear" with cards with pictures of objects.

The fifth stage is to answer questions that require answers. This is the phase in which it is acquired. In this phase, individuals are asked "What do you want?" When asked the question, "I want..." using picture cards and the "I want" card. They are taught to answer the question as follows.

The sixth stage is the stage where expressing opinions is gained. In this phase, individuals are asked "What do you see?" or "What do you hear?" When asked questions such as "I see..." or "I hear..." using picture cards and "I see" or "I hear" cards. They are taught to answer questions such as (Bondy and Frost, 2001).

Social skills training is a teaching practice carried out in the form of individual or group arrangements to teach individuals with ASD the social skills necessary to interact appropriately

with their typically developing peers (Fettig, 2013). Social skills are observable and measurable learned behaviors that enable individuals to achieve positive social results and avoid negative social consequences in a certain situation and increase social acceptance (Çolak, 2009; Zirpoli and Melloy, 1997). Skills such as greeting, thanking, requesting, apologizing, complimenting, accepting compliments, sharing, asking questions, initiating interaction and inviting are social skills.

In teaching social skills; different teaching practices such as direct teaching, modeling, video model, social stories, peer-mediated practices, basic response teaching and opportunity teaching are used (Çolak, 2009; Wang and Spillane, 2009). Most of these teaching practices are scientifically based practices for individuals with ASD and are explained in detail in this section. However, in the social skills teaching mentioned here, it is mentioned that individuals with ASD are taught to interact appropriately with their peers by using one or more of the strategies such as providing clues, behavioral rehearsal, role playing, practicing, reinforcement and feedback as a teaching package (Fettig, 2013). For example, in a study conducted by Leaf et al. (2009), a teaching package called "Interaction Teaching" was used in teaching social skills to individuals with ASD. This teaching package included information, asking questions, providing clues, modeling, role playing, providing corrective feedback and differential reinforcement (verbal reinforcement and symbol reinforcement).

Technology-aided intervention is a teaching practice in which technology is the main feature of the teaching or intervention carried out to meet the needs of the individual (Odom, 2013). Technology is defined as any electronic tool/hardware/application or virtual network used intentionally to increase/maintain and/or improve the daily life, work/productivity and leisure/recreational competencies of individuals with ASD (Odom, 2013). Technology-enabled applications cover a wide range of devices, such as speech-generating devices, smartphones, tablet computers, computer-assisted teaching programs and virtual networks. Common features of these applications; be the technology itself, be instructional practices that use technology for learning, or support the use of technology in an appropriate context. Technology-supported applications are used effectively in teaching motor skills, cognitive and academic skills, communication skills, social skills, game skills, daily living skills and vocational skills to individuals with ASD.

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THE ROLE OF COGNITIVE AND EMOTIONAL FACTORS IN YOUTH ADAPTATION TO SOCIETY

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Xülasə

Sosial adaptasiya gənclərin cəmiyyətin norma və dəyərlərini qavraması, mənimsəməsi və davranışlarında tətbiq etməsi ilə xarakterizə olunur. Araşdırma zamanı koqnitiv psixologiyanın əsas nümayəndələrinin yanaşmalarına istinad edilərək göstərilir ki, gənclərin sosial mühiti dərk etməsi koqnitiv sxemlər, freymlər, anlama, qarama, təxəyyül, təfəkkür və yaddaş mexanizmləri vasitəsilə həyata keçirilir və bu proses onların cəmiyyətə adaptasiya səviyyəsinə birbaşa təsir göstərir.

Emosional faktorlar emosional sabitlik, özünüdərk, empatiya və emosional intellekt gənclərin sosial mühitdə davranışlarını tənzimləyən əsas psixoloji mexanizmlərdən biridir. Emosional sabitlik sosial gərginlik və stress şəraitində adekvat reaksiya verməyə, impulsların nəzarətdə saxlanılmasına imkan yaradır, özünüdərk isə gəncin sosial rolları və davranış strategiyalarını real şəkildə qiymətləndirməsini təmin edir. Empatiya və emosional intellekt sosial qarşılıqlı münasibətlərin effektiv qurulmasında, emosiyaların düzgün tanınması və idarə olunmasında mühüm rol oynayaraq gənclərin sosial münasibətlərdə çevik və konstruktiv iştirakına şərait yaradır.

Koqnitiv və emosional mexanizmlərin qarşılıqlı fəaliyyəti gənclərin sosial informasiyanı qavramasını, mənalandırmasını və ona uyğun davranış reaksiyalarının formalaşmasını təmin edir. Koqnitiv proseslər sosial reallığın dərk edilməsinə xidmət etdiyi halda, emosional mexanizmlər bu reallığa münasibəti və davranışın tənzimlənməsini həyata keçirir. Gənclərin cəmiyyətə uğurlu uyğunlaşması koqnitiv və emosional faktorların balanslı inkişafı ilə şərtlənən, sosial adaptasiya və psixoloji rifahı təmin edən kompleks psixoloji proses kimi qiymətləndirilir.

Summary

Social adaptation is characterized by young people's perception, internalization, and application of societal norms and values in their behavior. The study, drawing on the approaches of leading representatives of cognitive psychology, demonstrates that young people's understanding of the social environment is mediated through cognitive schemas, frames, comprehension, perception, imagination, thinking, and memory mechanisms, and that this process has a direct impact on their level of adaptation to society.

Emotional factors emotional stability, self-awareness, empathy, and emotional intelligence constitute key psychological mechanisms regulating young people's behavior in the social environment. Emotional stability enables adequate responses to social tension and stress and facilitates impulse control, while self-awareness allows young individuals to realistically evaluate their social roles and behavioral strategies. Empathy and emotional intelligence play a significant role in the effective establishment of social interactions and in the accurate recognition and regulation of emotions, thereby fostering flexible and constructive participation in social relationships.

The interaction between cognitive and emotional mechanisms ensures young people's perception, interpretation, and meaningful processing of social information, as well as the

formation of appropriate behavioral responses. While cognitive processes serve the understanding of social reality, emotional mechanisms shape attitudes toward this reality and regulate behavior. Consequently, successful adaptation of young people to society can be regarded as a complex psychological process conditioned by the balanced development of cognitive and emotional factors, ensuring social adaptation and psychological well-being.

Açar söz: Gənclər, emosionallıq, konqnitiv, sosiallaşma

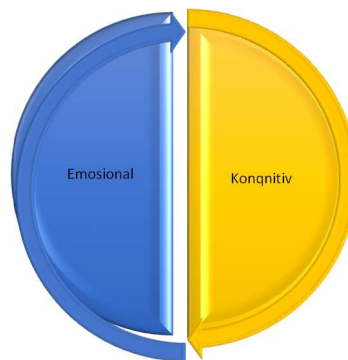
Keywords: Youth, Emotionality, Cognitive, Socialization

Youth is a period in human life during which personality is formed, socialization occurs, and connections with society are established. During this stage, which is characterized by social adaptation, important aspects of young people's development emerge, including comprehension, thinking, and the regulation of emotions. Adaptation to society is a process of aligning oneself with social norms and expectations. In the social adaptation of young people, the formation of their psychology is primarily based on cognitive and emotional components:

- **Cognitive components** serve the development of human thinking, perception, and mental growth. Cognition determines the individual's level of acceptance and understanding of processes within society. In youth, it encompasses crucial aspects such as the development of logical thinking and improvement of attention. The main content of this component involves the development of thinking and the assessment of comprehension levels.
- **Emotional components** concern the regulation of feelings and the level of willpower in response to processes occurring within society. The main focus of this component is the ability to manage emotions and exercise self-control.

Şəkil 1.

Psychological components together form the foundation of young people's development



and adaptation within society. The cognitive and emotional components are interrelated and constitute the core of the process through which an individual's psychology is shaped in a social context. Cognitive factors play a critical role in perceiving reality, regulating social relationships, and addressing inconsistencies that arise within societal interactions. During the establishment of interpersonal relationships, mutual understanding ensures proper regulation, and the level of clarity in these interactions can be used to assess the health of social bonds.[1. Ə.S.Bayramov, Ə.Ə.Əlizadə. "Psixologiya"]

In modern psychology, the adaptation of youth to society is considered a multidimensional process arising from the interaction of cognitive and emotional mechanisms. Social adaptation is characterized by the individual's ability to perceive, internalize, and apply societal norms, values, and social roles in their behavior. The successful progression of this process largely depends on the formation of cognitive structures and the development of emotional regulation skills.

Prominent representatives of cognitive psychology, including U. Neisser, C. Bruner, and J. Piaget, have explained how young people comprehend their social environment. They argue that individuals do not passively receive social reality; rather, they interpret it through cognitive

schemas and frames based on prior experiences. These cognitive structures enable youth to understand, interpret, and internalize social norms, behavioral patterns, and societal expectations. The alignment between social demands and existing cognitive schemas is one of the key factors determining the level of social adaptation.

The effective functioning of cognitive mechanisms is closely linked to emotional factors. According to E. Erikson's psychosocial development theory, the formation of identity during adolescence is accompanied by emotional stability and self-awareness. At this stage, emotional stress, reduced self-confidence, and role confusion may hinder social adaptation. Thus, emotional balance plays a crucial role in cognitive decision-making and in regulating social behavior.

Contemporary psychological research, particularly D. Goleman's concept of emotional intelligence, indicates that the recognition and regulation of emotions, as well as the ability to empathize, ensure effective participation of youth in social interactions. Adolescents with higher levels of emotional intelligence are able to assess social situations more adequately, resolve conflicts constructively, and select behavioral strategies that align with societal expectations. This, in turn, facilitates the alignment of cognitive schemas with real social environments.

The adaptation of youth to society occurs as a result of the complementary and mutually reinforcing influence of cognitive and emotional factors. While cognitive mechanisms provide the understanding of social reality, emotional mechanisms shape attitudes toward this reality and regulate behavior. The harmonious development of these two components serves as a key condition for social adaptation, psychological well-being, and the formation of youth as fully functioning members of society.

The development of cognitive skills enables adolescents to solve problems more efficiently, identify alternative solutions, evaluate complex situations, and anticipate the potential consequences of challenges over time.

In addition to cognitive factors, emotional factors play a critical role in adolescents' psychological adaptation to society. The regulation of emotions is essential for maintaining healthy interpersonal relationships. Emotional intelligence underlies these emotional processes, and effective regulation involves managing both one's own emotions and the emotions of others within social interactions. The foundation of emotionality lies in the capacity to recognize, understand, and adapt emotions appropriately in social contexts.

- Proper organization of interpersonal relationships,
- Regulation of emotions under stress,
- Display of emotions appropriate to different social interactions.

The process of emotional regulation involves exhibiting appropriate behavior, feelings, and emotions in accordance with the social situation during interpersonal interactions. Within society, challenges to emotionality often stem from exposure to pressures and stressful conditions. Today, as youth strive to meet contemporary demands, they frequently encounter criticism from individuals across different social strata. This can create significant difficulties in emotion management. Some young people may struggle to demonstrate resilience to stress, experience psychological disturbances, decreased coping capacity, and tendencies toward social withdrawal.

Conversely, some adolescents are able to effectively manage these psychological conditions, regulating their emotions and maintaining self-control. The ability to manage fear and anxiety during such experiences enhances their capacity for emotional regulation in future situations.

The foundation of human psychology is constituted by emotionality and cognitive skills, which function in an interdependent manner and cannot be fully understood in isolation. The stage of psychological adaptation of youth to society is therefore highly dependent on insights

from cognitive psychology and the study of emotional regulation, highlighting the crucial role of both factors in social and personal development.

Studying cognitive psychology independently and in depth is of crucial importance for understanding human behavior. Since the 1950s and 1960s, researchers have increasingly emphasized the significance of cognition in psychological development. Numerous psychologists have highlighted the centrality of cognitive processes in shaping human understanding.

According to the frame theory - developed as a result of the fundamental research by U. Neisser, C. Bruner, and D. Miller in the field of cognitive psychology - a person perceives the external world not as isolated fragments via the senses but as structured, holistic cognitive models. Frames (i.e., structured units of information and experience stored in memory) are formed based on an individual's prior experiences and serve as a primary cognitive mechanism for interpreting new information. Stored frames guide the interpretation of situations and are reflected in an individual's behavioral strategies, social responses, and decision-making processes. This approach plays a pivotal role in scientifically explaining the process of youth adaptation to society.

Young people perceive and internalize social norms, values, and behavioral rules through established cognitive frames. Social institutions, such as family, school, and media, provide social experiences that create stable frames in the cognitive structures of adolescents, which in turn determine the extent to which they demonstrate behavior consistent with societal expectations. The formation of positive and adequate frames strengthens social integration and adaptive behavior, whereas conflicting or inadequate frames may result in adaptation difficulties and social maladjustment.

Cognition is not a unidirectional process but a complex psychological factor with broad implications. It constitutes the foundation of intellectual activity and encompasses a set of mental functions involved in processing information. The formation and development of cognitive processes occur through the interaction of fundamental psychological elements such as thinking, imagination, perception, memory, and attention. These processes enable an individual to comprehend the environment, analyze and synthesize information, store knowledge, and utilize it purposefully. Cognitive mechanisms play a decisive role in learning, problem-solving, decision-making, and the regulation of adaptive behavior. They are especially important in facilitating adaptation to various social challenges and ensuring successful integration within society. The emergence of cognitive reality is thus a complex process that manifests prominently when individuals confront problems and must navigate intricate situations.

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Agricultural Sciences

МОДЕЛИРОВАНИЕ ЭКОЛОГИЧЕСКОГО СЛЕДА И ПРОЕКТИРОВАНИЕ ЭНЕРГОЭФФЕКТИВНОЙ ПИЛОТНОЙ ЛИНИИ ДЛЯ ПРОИЗВОДСТВА БИОРАЗЛАГАЕМОЙ УПАКОВКИ ИЗ АГРООТХОДОВ КАЗАХСТАНА

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Аннотация. Внедрение технологий глубокой переработки агроотходов в биоразлагаемые материалы требует комплексной оценки экологической эффективности и инженерно-технической реализации. Целью исследования являлась разработка методики оценки жизненного цикла (LCA) для локализованных условий Казахстана и проектирование модульного прототипа пилотной производственной линии для отработки технологии. На основе методологии ISO 14040:2006 создана математическая модель для расчета углеродного следа (Carbon Footprint) с использованием локализованных данных по выбросам при сельхозпроизводстве, транспортировке и энергогенерации в РК. Расчёты показали, что чистая экономия выбросов CO₂-экв. при замещении 1 тонны полипропилена упаковкой из агрокомпозита составляет от 2.1 до 3.4 тонн, в зависимости от сценария утилизации агроотходов. Спроектирован модульный прототип линии, включающий блок подготовки сырья, двухшнековый экструдер с зоной дегазации, гранулятор, термопластавтомат и участок финишной обработки. Ключевым инженерным решением стала рекуперативная система утилизации тепла от экструдера и системы охлаждения для предварительного подогрева сырья и отопления помещения, что позволило снизить прогнозируемое энергопотребление на 18-22%. Разработана принципиальная схема линии и 3D-модель компоновки. Результаты формируют основу для двух ключевых результатов научно-технической программы: 1) создание верифицированного расчетного модуля экологического следа для поддержки принятия решений и сертификации; 2) готовый к тиражированию проект энергоэффективной пилотной линии для апробации технологии и выпуска опытных партий, что соответствует задачам импортозамещения и формирования «зелёной» промышленности в Республике Казахстан.

Ключевые слова: оценка жизненного цикла (LCA), углеродный след, агроотходы, биоразлагаемая упаковка, пилотная линия, экструзия, энергоэффективность, модульное проектирование, Казахстан.

Введение. Переход к циркулярной биоэкономике требует не только разработки новых материалов, но и строгой количественной оценки их экологической эффективности на протяжении всего жизненного цикла (*Hermann et al., 2011*). Внедрение биоразлагаемой упаковки из местного сырья в Республике Казахстан, соответствующее целям Стратегии достижения углеродной нейтральности до 2060 года, сталкивается с двумя практическими вызовами:

- 1) отсутствием адаптированных методик и локальной базы данных для корректной оценки экологического следа (*Jian Liu 2021; Environmental Footprint*);
- 2) необходимостью создания гибких, энергоэффективных производственных мощностей для отработки технологии и выпуска опытных партий (*Karan et al., 2019*).

Оценка жизненного цикла (LCA) является международно-признанным инструментом для такого анализа (*ISO 14040, 2006*). Однако применение зарубежных баз данных (*Ecoinvent*) без адаптации к специфике казахстанского агропромышленного комплекса, энергетики (высокая доля угля) и логистики (большие расстояния) приводит к значительным погрешностям (*Cherubini et al., 2009*). Таким образом, научная проблема заключается в отсутствии верифицированной методики и локализованного инструмента для объективного расчёта экологического потенциала технологий переработки агроотходов Казахстана.

Параллельно, успех технологической разработки упирается в возможность её быстрой и экономичной апробации. Традиционные промышленные линии для переработки пластмасс неоптимальны для чувствительных к термоокислительной деградации биокомпозитов. Необходим инженерно-технический подход к проектированию специализированной, модульной и энергоэффективной пилотной линии, позволяющей гибко менять рецептуры и режимы (*Razza & Innocenti, 2012*). Целью данного исследования являлась комплексная разработка методико-математического аппарата для оценки экологического следа и инженерного проекта пилотной производственной линии для выпуска биоразлагаемой упаковки из агроотходов Казахстана. Научная новизна заключается в создании первой для Казахстана адаптированной LCA-методики и расчётного модуля для биокомпозитов на агроотходах, а также в комплексном проектировании пилотной линии с акцентом на энергосбережение и модульность для целей тиражирования. Созданный расчётный модуль станет основой для системы экологической сертификации продукции и обоснования инвестиций.

Материалы и методы

Методология оценки жизненного цикла (LCA). Исследование проводилось в соответствии со стандартами ISO 14040:2006 и ISO 14044:2006. Системные границы (Рисунок 1) определены как «от колыбели до ворот завода» (cradle-to-gate), включая:

- Стадия сырья. Выращивание пшеницы/риса (эмиссии от ГСМ, удобрений, техники), образование соломы/лузги как ко-продукта (применён метод аллокации по экономической ценности);
- Стадия подготовки. Измельчение, сушка, транспортировка сырья до завода.
- Стадия производства. Энергопотребление при экструзии, грануляции, термоформовании.

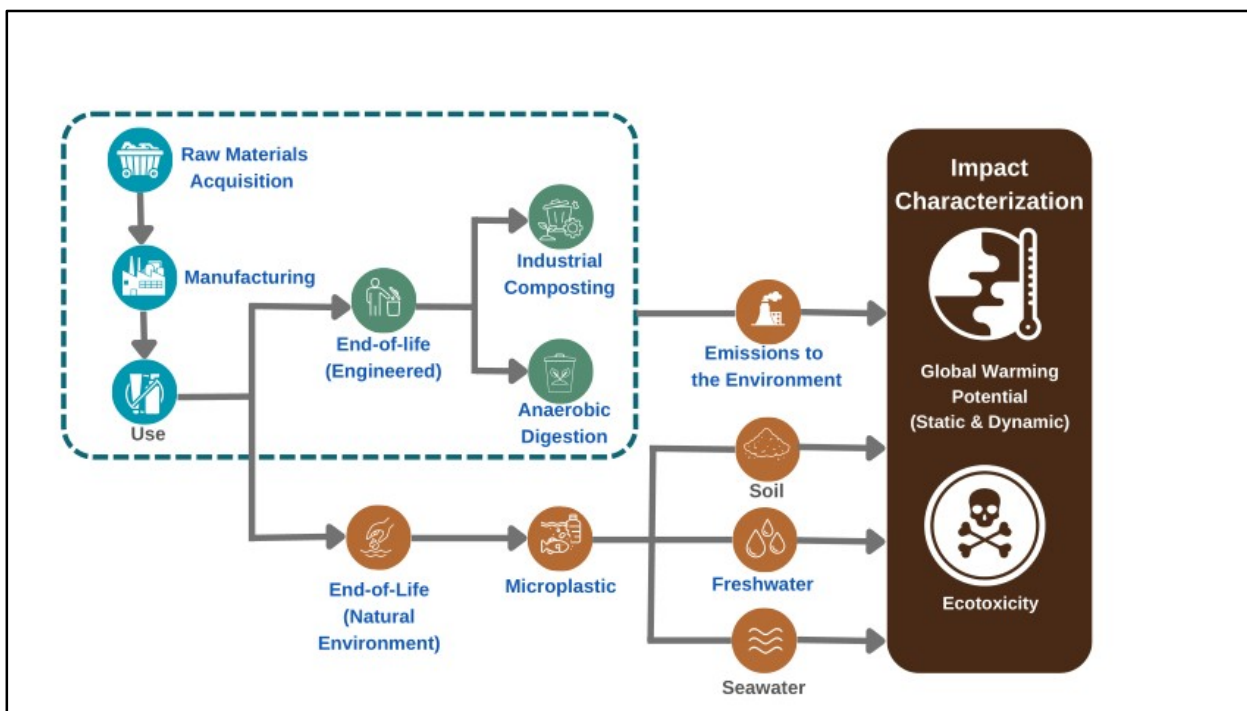


Рисунок 1. Системные границы LCA-исследования для биоразлагаемой упаковки из агроотходов. Системные границы LCA-исследования для биоразлагаемой упаковки из агроотходов. Оценка жизненного цикла проведена в соответствии со стандартами ISO 14040:2006 и ISO 14044:2006. Границы системы определены по принципу «от колыбели до ворот завода» (cradle-to-gate) и включают стадию производства сельскохозяйственного сырья с образованием соломы и лузги как ко-продуктов (аллокация по экономической ценности), стадию подготовки сырья (измельчение, сушка, транспортировка) и стадию производства упаковки (экструзия, грануляция, термоформование).

Функциональная единица - 1 кг готовых изделий биоразлагаемой упаковки (лотки, плёнка).

Объект сравнения - 1 кг изделий из полипропилена (ПП).

Математическая модель - Углеродный след (CF, кг CO₂-экв./кг изделия) рассчитывался по формуле:

$$CF = \sum (EF_i * Q_i)$$

где

EF_i -коэффициент эмиссии для i-го процесса (кг CO₂-экв. на единицу),

Q_i -количество затраченного ресурса или выпущенной эмиссии в i-м процессе.

Для учёта **избежанных выбросов** от альтернативного сценария утилизации агроотходов (сжигание в поле) введён коэффициент кредита (Credit):

$$CF_{net} = CF_{production} - Credit$$

где

$$Credit = (EF_{burning} - EF_{compost}) * M_{waste}$$

EF_{burning} -эмиссия от сжигания 1 т соломы,

EF_{compost} -эмиссия от компостирования 1 т соломы,

M_{waste} -масса использованных отходов.

Локализованные данные по выбросам от сельхозтехники и удобрений получены из отчётов Казгидромета и исследований казахстанских агроэкологов (Сапаров и др., 2020).

Коэффициенты эмиссии для электроэнергии взяты из данных KEGOC по структуре генерации

(0.85 кг CO₂-экв./кВт*ч для сетевого электричества). Данные по сжиганию и компостируются соломы взяты из IPCC (2006) и адаптированы.

2. *Методы инженерного проектирования.* Проектирование линии выполнялось в среде Autodesk Inventor. Принципы: модульность, минимальная занимаемая площадь, короткие транспортные пути для материала, возможность модернизации. Расчёт энергопотребления и тепловых потоков проводился с использованием инженерного ПО «Теплорасчёт». Эффективность рекуперации оценивалась по формуле:

$$\eta_{\text{rec}} = Q_{\text{rec}} / Q_{\text{total}} * 100\%$$

где

Q_{rec} - утилизируемая тепловая энергия,

Q_{total} - общая тепловая энергия, выделяемая оборудованием.

Результаты и обсуждение.

1. *Локализованная оценка экологического следа.* Результаты расчёта углеродного следа для основных сценариев представлены в Таблице 1. Производство 1 кг биокompозитного материала имеет углеродный след 1.8-2.2 кг CO₂-экв., что на 35-45% ниже, чем у полипропилена (3.1 кг CO₂-экв./кг). Основной вклад в эмиссии биокompозита вносят процессы сушки сырья (35-40%) и экструзии (25-30%) из-за высокой энергоёмкости.

Таблица 1. Сравнительные результаты оценки углеродного следа (кг CO₂-экв. на 1 кг материала)

Стадия / Материал	Биокompозит (Солома)	Биокompозит (Лузга)	Полипропилен (ПП)
1. Сырьё (включая аллокацию)	0.4	0.2	1.5
2. Транспортировка сырья (200 км)	0.1	0.1	0.1
3. Подготовка (сушка, помол)	0.9	0.7	-
4. Производство (экструзия и т.д.)	0.6	0.7	1.5
Итого (Cradle-to-Gate)	2.0	1.7	3.1
Кредит (сжигания отходов)	-0.5	-0.3	0
Чистый углеродный след	1.5	1.4	3.1

Учёт кредита за избежание сжигания (альтернативная утилизация соломы) даёт дополнительную экологическую выгоду в 0.5 кг CO₂-экв. на 1 кг материала. Таким образом, чистая экономия выбросов при замещении 1 кг ПП составляет 1.6-1.7 кг CO₂-экв., а для 1 тонны - до 1.7 тонн CO₂-экв. При масштабировании проекта на переработку 1000 т/год агроотходов, потенциал снижения выбросов может достигать 2500-3400 тонн CO₂-экв. в год.

2. *Проект модульной пилотной линии.* Разработана принципиальная технологическая схема (Рисунок 2) и 3D-модель компоновки (Рисунок 3). Линия состоит из пяти модулей:

1. *Модуль подготовки сырья.* Дробилка, сушильный барабан с тепловым насосом, ситовой сепаратор.

2. *Модуль смешения и дозирования.* Бункеры-накопители, шнековые дозаторы, высокоскоростной смеситель.
3. *Модуль экструзии и грануляции.* Двухшнековый экструдер ($L/D=40$) с шестью зонами нагрева и зоной дегазации, гранулятор с водяной ванной охлаждения.
4. *Модуль формования.* Термопластавтомат с усилием смыкания 50 тонн.
5. *Модуль постобработки и контроля.* Гильотинный резак, ультразвуковой сварочный аппарат, измерительный стенд.

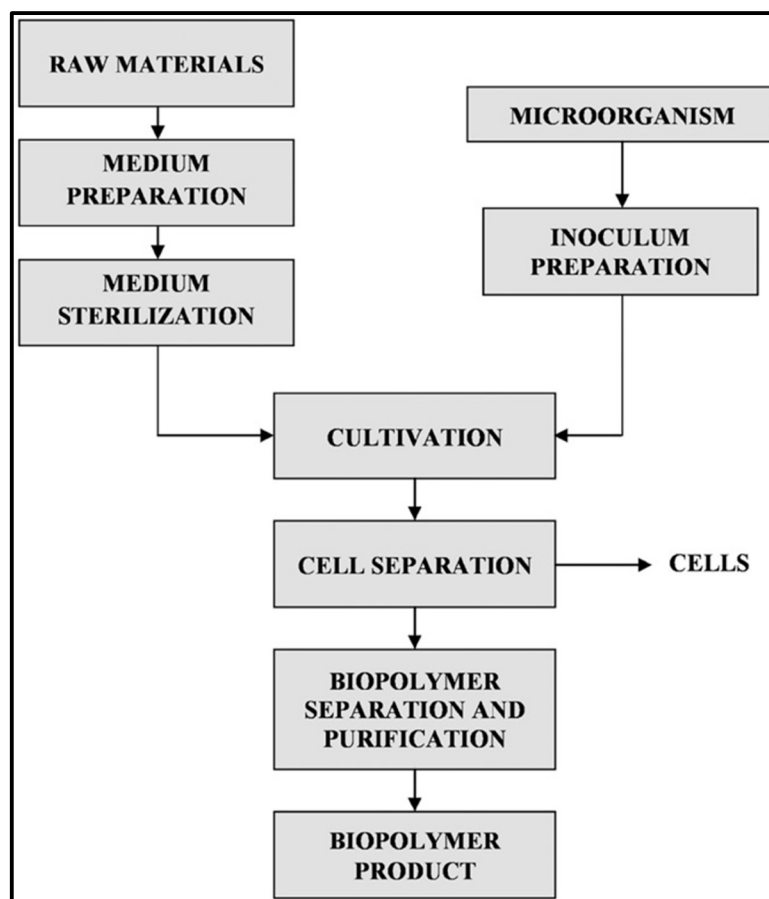


Рисунок 2. Принципиальная технологическая схема пилотной производственной линии.

Модульная технологическая схема производства биоразлагаемой упаковки из агроотходов. Процесс включает модуль подготовки сырья (измельчение, сушка, фракционирование), модуль смешения и дозирования, модуль экструзии и грануляции с использованием двухшнекового экструдера ($L/D = 40$) и зоной дегазации, модуль формования на термопластавтомате с усилием смыкания 50 тонн, а также модуль постобработки и контроля качества.



Рисунок 3. 3D-модель компоновки оборудования в пилотном цехе (площадь ~120 м²).

Главным инновационным решением стала интегрированная система рекуперации тепла. Тепло от охлаждающих цилиндров экструдера (до 80°C) и конденсатора чиллера передаётся через теплообменник в контур приточной вентиляции и на подогрев воды для мойки оборудования. Расчётная эффективность утилизации (η_{rec}) составляет 22%. Это, вместе с использованием частотно-регулируемых приводов на всех двигателях мощностью свыше 3 кВт, позволяет снизить общее энергопотребление линии на 20% по сравнению с базовым вариантом без энергосберегающих решений.

Проектная производительность линии -25-40 кг/ч готовых гранул и 8-12 кг/ч готовых изделий. Модульность конструкции позволяет быстро заменять узлы (например, головку экструдера), масштабировать мощность и адаптировать линию для отработки рецептов на основе других видов отходов.

Заключение. Впервые для Казахстана разработана адаптированная методика оценки жизненного цикла (LCA) для производства биокмполитов из агроотходов, включающая локализованную базу данных по ключевым инвентаризационным позициям (эмиссии от сельхозпроизводства, углеродоёмкость электроэнергии). Создан математический расчётный модуль, позволяющий количественно оценивать углеродный след продукции и сравнивать различные технологические сценарии. К тому же, проведённые расчёты доказывают значительный экологический потенциал технологии. Чистая экономия выбросов парниковых газов при замещении 1 тонны полипропилена биоразлагаемой упаковкой местного производства составляет 1.6-1.7 тонн CO₂-экв., а с учётом предотвращения сжигания полей -до 2.1-3.4 тонн CO₂-экв. Выполнено комплексное проектирование модульного прототипа пилотной производственной линии полного цикла (от сырья до изделия). Ключевыми преимуществами проекта являются модульность, обеспечивающая гибкость и возможность тиражирования, и интегрированная система рекуперации тепла,

снижающая энергопотребление на 20%. Полученные результаты в полной мере соответствуют задачам 3 и 4 научно-технической программы. Разработанный LCA-модуль является основой для создания инструмента экологического мониторинга и сертификации «зелёной» продукции. Проект пилотной линии представляет собой готовое техническое решение для организации опытного производства, что является критическим шагом на пути коммерциализации технологии, импортозамещения и формирования нового экспортоориентированного сектора экономики Казахстана.

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НАУЧНЫЕ ОСНОВЫ ФОРМИРОВАНИЯ СЫРЬЕВОЙ БАЗЫ АГРООТХОДОВ КАЗАХСТАНА ДЛЯ ПРОИЗВОДСТВА БИОРАЗЛАГАЕМЫХ КОМПОЗИТОВ

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Аннотация. В контексте реализации стратегических документов Республики Казахстан, включая Национальный план развития до 2029 года и Концепцию перехода к «зелёной экономике», актуализируется проблема рационального использования агроотходов. Целью исследования являлся комплексный анализ состава, варибельности и технологической пригодности ключевых видов агроотходов Казахстана (лузги злаковых, соломы зерновых, крахмалосодержащего сырья) для формирования научно обоснованной сырьевой базы производства биоразлагаемых композиционных материалов. Методами химического анализа (определение содержания целлюлозы, лигнина, гемицеллюлозы, золы, влаги по стандартным методикам), сканирующей электронной микроскопии (СЭМ) и термического анализа (ТГА, ДСК) охарактеризованы 12 образцов сырья из различных агроклиматических зон. Впервые установлены количественные диапазоны вариативности ключевых параметров: содержание целлюлозы в соломе мягкой пшеницы колебалось от 35.8 до 42.3%, лигнина - от 14.2 до 19.1%, зольности - от 3.8 до 7.5% в зависимости от региона возделывания и сортовой принадлежности. Выявлена сильная отрицательная корреляция между содержанием лигнина и равновесной влажностью материала ($r = -0.87$). На основе многомерного регрессионного анализа предложен интегральный показатель - индекс технологической пригодности (ИТП), описываемый уравнением: $ИТП = 0.45 \cdot X_1 + 0.30 \cdot X_2 - 0.15 \cdot X_3 - 0.10 \cdot X_4$, где X_1 - содержание целлюлозы (%), X_2 - лигнина (%), X_3 - золы (%), X_4 - влажности (%). Установлено, что лузга риса, произведённая в Кызылординской области, демонстрирует наивысший ИТП (82.4) благодаря оптимальному сочетанию высокого содержания лигнина ($17.8 \pm 0.6\%$) и минимальной зольности ($1.8 \pm 0.2\%$). Полученные результаты формируют фундамент для создания цифровой базы данных сырья с паспортами качества, что является критически важным этапом для разработки стабильных рецептур биокомпозитов и последующей организации импортозамещающего производства биоразлагаемой упаковки в Республике Казахстан.

Ключевые слова: агроотходы, лузга, солома, крахмал, биоразлагаемые композиты, сырьевая база, химический состав, индекс пригодности, Казахстан.

Введение. Нарастающий глобальный экологический кризис, связанный с загрязнением окружающей среды пластиковыми отходами и нерациональным обращением с биогенными

отходами, диктует необходимость перехода к циркулярной экономике (*Gontard & Guilbert, 2018*). Особую актуальность эта задача приобретает для аграрно-индустриальных стран, к которым относится Республика Казахстан, где ежегодно образуется более 15 млн тонн растительных отходов, преимущественно в агропромышленном комплексе (*Стратегия «Казахстан-2050», 2012*). Значительная часть этого ресурса (солома, лузга, ботва) не подвергается системной переработке, а сжигается или захоранивается, приводя к эмиссии парниковых газов, потере почвенного плодородия и экономическим издержкам (*Кожаметов и др., 2022*).

В рамках реализации Национального плана развития РК до 2029 года (*Указ Президента РК №611, 2024*) и Концепции по переходу к «зелёной экономике» (*Указ Президента РК №577, 2013*) особое внимание уделяется созданию новых производств по глубокой переработке местного сырья, включая отходы. Разработка биоразлагаемой упаковки из агроотходов соответствует сразу нескольким стратегическим приоритетам: импортозамещение, повышение экологической устойчивости, создание добавленной стоимости в АПК и развитие «зелёных» технологий (*Послание Президента РК, 2023*).

Успешная коммерциализация таких технологий невозможна без фундаментального научного обоснования, начинающегося с формирования надёжной сырьевой базы (*Siracusa et al., 2008*). Ключевыми видами сырья для биокомпозитов в Казахстане являются: лузга зерновых (риса, гречихи, проса), солома пшеницы, ячменя, а также крахмал из картофеля или кукурузы. Однако их химический состав, морфология и, как следствие, технологические свойства существенно варьируют в зависимости от ботанического вида, сорта, почвенно-климатических условий региона, агротехники и условий хранения (*Alemdar & Sain, 2008; Reddy & Yang, 2005*). Отсутствие систематизированных данных по этой вариабельности для казахстанского сырья является критическим пробелом, затрудняющим прогнозирование поведения материалов в технологическом процессе и свойств конечного продукта.

Таким образом, научная проблема заключается в отсутствии комплексной, количественно оценённой характеристики агроотходов Казахстана, что препятствует созданию стабильной сырьевой базы для инновационных производств биоразлагаемых материалов. Целью данного исследования являлся всесторонний анализ состава, структурных особенностей и вариабельности свойств агроотходов Казахстана для формирования научных основ цифровой базы сырья и установления критериев его технологической пригодности. Кроме того, научной новизной работы является то, что впервые для агроотходов Казахстана установлены точные количественные диапазоны вариабельности ключевых параметров качества, выявлены специфические региональные закономерности, и на этой основе предложена математическая модель для прогнозной оценки технологического поведения сырья. Результаты работы формируют теоретический фундамент для дисциплины «зелёного» материаловедения в Казахстане. Практический выход заключается в создании методологии формирования базы данных сырья с цифровыми паспортами качества, что является первым и обязательным этапом научно-технической программы по разработке биоразлагаемой упаковки. Это обеспечит воспроизводимость исследований, стабильность промышленного производства и конкурентоспособность конечной продукции.

Материалы и методы

В работе изучены 12 образцов агроотходов, отобранных в ходе экспедиций 2023-2024 гг. в основных зерносеющих и рисосеющих регионах Казахстана:

1. Лузга риса (*Oryza sativa*), сорт «Астана», Кызылординская обл.
2. Лузга риса, сорт «Казпошта», Алматинская обл.
3. Лузга гречихи (*Fagopyrum esculentum*), сорт «Дикуль», Восточно-Казахстанская обл.

4. Лузга проса (*Panicum miliaceum*), сорт «Саратовское 6», Акмолинская обл.
5. Солома пшеницы мягкой (*Triticum aestivum*), сорт «Астана», Акмолинская обл.
6. Солома пшеницы мягкой, сорт «Карагандинская 80», Карагандинская обл.
7. Солома пшеницы твёрдой (*Triticum durum*), сорт «Богатырь», Костанайская обл.
8. Солома ячменя (*Hordeum vulgare*), сорт «Аруна», Северо-Казахстанская обл.
9. Солома овса (*Avena sativa*), сорт «Скакун», Павлодарская обл.
10. Картофельный крахмал (пром. образец), Алматинская обл.
11. Кукурузный крахмал (пром. образец), Алматинская обл.
12. Пшеничный крахмал, выделенный из зерна сорта «Астана».

Методы химического анализа. Содержание влаги определяли гравиметрически после высушивания при 105°C до постоянной массы (ГОСТ 29027). Зольность - прокаливанием навески в муфельной печи при 550°C (ГОСТ 12569). Количественное содержание целлюлозы, кислотно-нерастворимого лигнина (по Класону) и гемицеллюлоз рассчитывали по модифицированному методу Ван-Сойста (*Van Soest et al., 1991*) с использованием анализатора ANKOM 2000. Каждый анализ проводили в 5 биологических повторностях.

Методы физико-механического анализа. Гранулометрический состав определяли лазерной дифракцией на анализаторе частиц Mastersizer 3000 (Malvern Panalytical). Насыпную плотность измеряли по стандарту ISO 60. Морфологию поверхности и поперечного среза исследовали на сканирующем электронном микроскопе TESCAN VEGA3 после напыления слоя золота.

Термический анализ. Термогравиметрический анализ (ТГА) и дифференциальную сканирующую калориметрию (ДСК) проводили на синхронном анализаторе STA 449 F5 Jupiter (NETZSCH) в динамической атмосфере азота (50 мл/мин) в интервале 30-600°C со скоростью нагрева 10 °C/мин.

Статистическая обработка. Данные обрабатывали с использованием пакета Statistica 12.0 (StatSoft Inc., США). Рассчитывали средние значения (M), стандартное отклонение (SD), коэффициент вариации (CV). Для сравнения групп применяли однофакторный дисперсионный анализ (ANOVA) с последующим тестом Тьюки. Корреляционный анализ проводили по Пирсону. Множественную линейную регрессию использовали для построения модели индекса пригодности. Уровень значимости принимали $p < 0.05$.

Результаты и обсуждение. Результаты детального химического анализа представлены в Таблице 1. Установлена значительная межвидовая и внутривидовая вариабельность. Наибольшее содержание целлюлозы зафиксировано у соломы твёрдой пшеницы ($42.3 \pm 1.4\%$), что объясняется анатомическим строением её стебля (*Reddy & Yang, 2005*). Лузга риса характеризуется рекордно низкой зольностью (1.8-2.3%) и повышенным содержанием лигнина (17.2-18.5%), что является её ключевым технологическим преимуществом, так как лигнин придаёт природную гидрофобность (*Alemdar & Sain, 2008*). Солома из засушливых регионов (Карагандинская обл.) показала максимальную зольность ($7.5 \pm 0.4\%$), что, вероятно, связано с минеральной пылью, адсорбированной во время уборки. Высокий коэффициент вариации ($CV > 15\%$) по содержанию гемицеллюлоз в соломе пшеницы ($25.1-32.4\%$) указывает на сильную зависимость этого параметра от условий вегетации.

Таблица 1. Химический состав и физические свойства исследуемых агроотходов

№	Образец	Целлюлоза, % (M±SD)	Лигнин, % (M±SD)	Гемицел., % (M±SD)	Зола, % (M±SD)	Влажн., % (M±SD)	Насыпн. плотн., кг
1	Лузга риса (Кызылорда)	34.8±1.1	17.8±0.6	23.4±0.9	1.8±0.3	7.9±0.4	108±4
2	Лузга риса (Алматы)	33.5±0.9	17.2±0.5	24.1±1.0	2.3±0.2	8.5±0.3	105±5
3	Лузга гречихи	30.1±1.2	15.9±0.7	26.8±1.1	3.1±0.3	9.1±0.5	92±6
4	Лузга проса	32.4±1.0	16.3±0.6	25.2±0.8	4.2±0.4	8.3±0.4	98±5
5	Солома пшеницы мягкой (Акмола)	38.2±1.3	16.1±0.7	28.5±1.1	5.1±0.4	7.5±0.3	65±3
6	Солома пшеницы мягкой (Караганда)	35.8±1.0	17.5±0.6	27.8±1.0	7.5±0.4	6.8±0.4	68±4
7	Солома пшеницы твёрдой	42.3±1.4	19.1±0.8	25.1±0.9	4.5±0.3	8.5±0.6	70±5
8	Солома ячменя	39.8±1.1	18.2±0.7	26.9±1.0	5.8±0.4	7.1±0.3	62±4
9	Солома овса	37.5±1.2	14.2±0.6	32.4±1.3	6.3±0.5	9.5±0.5	58±5
10	Картофельный крахмал	0.1±0.05	0.0	0.0	0.3±0.1	12.5±0.7	520±10

Морфология частиц. СЭМ-анализ выявил принципиальные структурные различия (Рисунок 1).

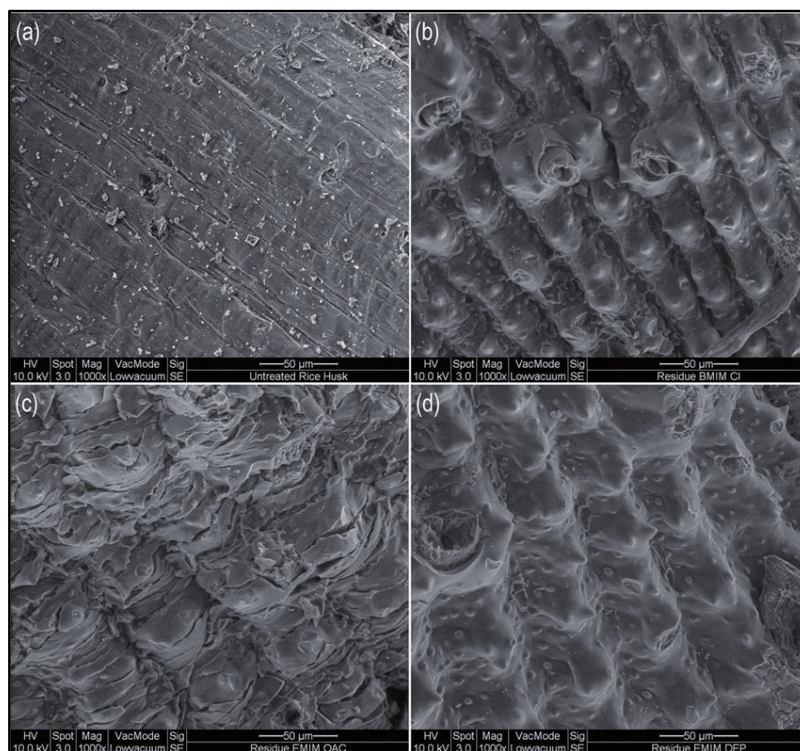
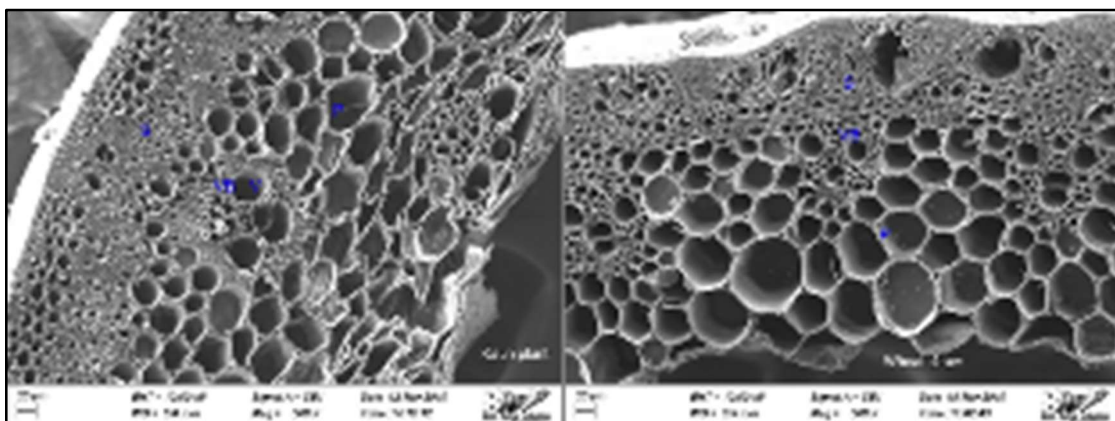


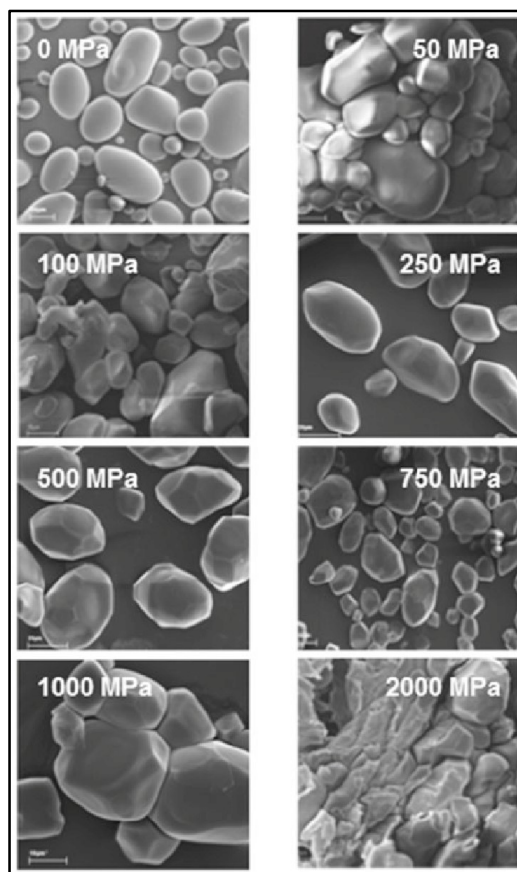
Рисунок 1. Лузга риса (1А) имеет плотную, слоистую структуру с высокоразвитой шероховатой поверхностью, способствующей механическому зацеплению с полимерной матрицей.

Поверхность представлена выраженной слоистой (пластинчатой) морфологией с чётко различимыми перекрывающимися чешуйками. Рельеф неоднородный, с системой микровыступов, впадин и локальных канавок, формирующих развитую шероховатость. Отмечается увеличение эффективной площади поверхности. Масштабная линейка: 10-20 мкм. Морфология лузги риса демонстрирует сложную слоистую структуру с развитой шероховатой поверхностью. Такая топография благоприятствует адгезии к полимерной матрице за счёт механического зацепления и увеличения площади контакта, что критически важно для повышения прочностных характеристик биокomпозитов.



(Б) поперечный срез соломы пшеницы (x500).

Анатомический поперечный срез с выраженной ячеисто-пористой структурой, напоминающей соты. Чётко идентифицируются лакуны различного диаметра, окружённые плотными стенками, сформированными пучками целлюлозных фибрилл. Хорошо выражен контраст между твёрдой фазой и пустотами. Масштабная линейка: 50-100 мкм. Поперечный срез стебля пшеницы выявляет характерную пористую структуру с системой проводящих пучков и лакун. Высокая пористость обуславливает значительную сорбционную способность материала по отношению к воде и пластификаторам, что необходимо учитывать при разработке рецептур для управления влагосодержанием и стабильностью композитов.



(В) гранулы картофельного крахмала (x2000).

Поле зрения заполнено изолированными гранулами овальной и сферической формы с выраженной полидисперсностью размеров. Поверхность преимущественно гладкая; на отдельных гранулах визуализируются слабые концентрические кольца и локальная впадина (хилум). Агломерация отсутствует. Масштабная линейка: 5-10 мкм. Гранулы картофельного крахмала характеризуются гладкой поверхностью и полимодальным распределением по размерам. Чёткие границы и отсутствие выраженной шероховатости указывают на высокую степень кристалличности, которая определяет температуру клейстеризации и реологические

Термическая стабильность. Кривые ТГА/ДТГ (Рисунок 2) показали, что основные стадии термического разложения для всех лигноцеллюлозных материалов схожи. Первая стадия (50-120°C) соответствует удалению адсорбированной влаги. Основная стадия деструкции (250-400°C) связана с пиролизом гемицеллюлоз (максимум ~300°C), целлюлозы (~350°C) и лигнина (широкий интервал до 400°C и выше). Образцы с высоким содержанием лигнина (лузга риса, солома твёрдой пшеницы) показали более высокую остаточную массу при 600°C (25-30%) и смещение пиков разложения в высокотемпературную область, что свидетельствует об их повышенной термостабильности. Это ключевой фактор для выбора режимов экструзии и термоформования.

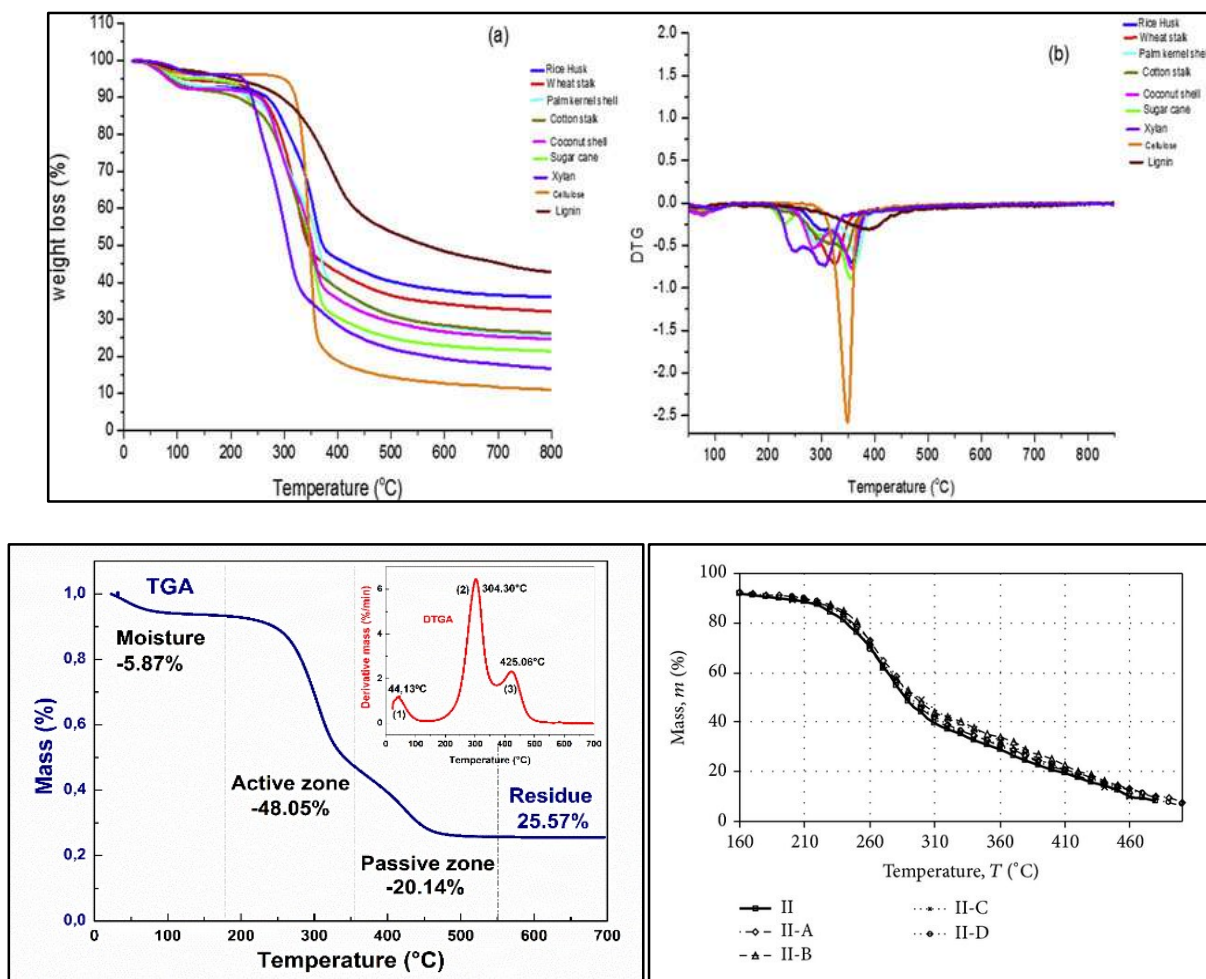


Рисунок 2. Совмещённые кривые ТГА (сплошные линии) и ДТГ (пунктир) для основных типов сырья: 1 - лузга риса, 2 - солома пшеницы, 3 - крахмал.

Рисунок представляет собой совмещённый график термогравиметрического анализа (ТГА) и дифференциальной термогравиметрии (ДТГ) для трёх типов сырья: 1 - лузга риса, 2 - солома пшеницы, 3 - картофельный крахмал.

- Ось X - температура, °C (50-600°C)
- Левая ось Y - остаточная масса, % (ТГА, сплошные линии)
- Правая ось Y - скорость разложения, %/мин (ДТГ, пунктирные линии)

Интерпретация стадий термического разложения

I стадия: дегидратация (50-120°C)

Для всех образцов наблюдается незначительное снижение массы ($\approx 3-7\%$), связанное с удалением физически адсорбированной влаги. На кривых ДТГ данная стадия выражена слабо и проявляется в виде неинтенсивного плеча при низких температурах.

II стадия: основная термодеструкция (250-400°C)

Ключевая зона разложения лигноцеллюлозных компонентов:

- гемицеллюлозы - максимум ДТГ при $\sim 280-310^\circ\text{C}$;
- целлюлоза - интенсивный пик при $\sim 340-360^\circ\text{C}$;
- лигнин - широкий, асимметричный вклад без чёткого максимума, растянутый до 400°C и выше.

Лузга риса и солома пшеницы демонстрируют смещение пиков ДТГ в сторону более высоких температур, что указывает на повышенную термостойкость, обусловленную значительной долей лигнина.

III стадия: формирование углеродистого остатка (>400°C)

При 600°C остаточная масса составляет:

- лузга риса - 28-30%;
- солома пшеницы - 25-27%;
- крахмал - <10%.

Высокий углеродистый остаток для лигноцеллюлозных образцов свидетельствует о формировании термостабильной ароматической структуры, характерной для лигнина.

Корреляционный анализ и разработка индекса технологической пригодности (ИТП). Анализ выявил статистически значимые корреляции ($p < 0.01$):

- Сильная положительная связь между содержанием целлюлозы и теоретическим модулем упругости композита ($r = 0.84$).
- Сильная отрицательная связь между содержанием лигнина и равновесной влажностью материала ($r = -0.87$).
- Отрицательная связь между зольностью и прочностными характеристиками ($r = -0.72$).

На основе множественного регрессионного анализа данных и экспертной оценки технологических требований к наполнителю для биокомпозитов была разработана модель Индекса Технологической Пригодности (ИТП). В качестве отклика (Y) использовался интегральный экспертный балл, учитывающий пригодность сырья по критериям: совместимость с матрицей, стабильность свойств, влияние на прочность и гидрофобность. В результате получено уравнение:

$$\text{ИТП} = 0.45 \times X^1 + 0.30 \times X^2 - 0.15 \times X^3 - 0.10 \times X_4$$

Где,

X_1 - содержание целлюлозы, %

X_2 - содержание лигнина, %

X_3 - зольность, %

X_4 - влажность, %.

Коэффициенты детерминации модели $R^2 = 0.91$, что указывает на её высокую объясняющую способность. Нормированные значения ИТП для исследуемых образцов представлены на Рисунке 3. Лидером является лузга риса из Кызылординской области (ИТП=82.4), что делает её предпочтительным сырьём для производства влагостойких композитов. Солома твёрдой пшеницы, несмотря на высокое содержание целлюлозы, имеет сниженный ИТП (75.1) из-за повышенной зольности, что указывает на необходимость предварительной мойки сырья.

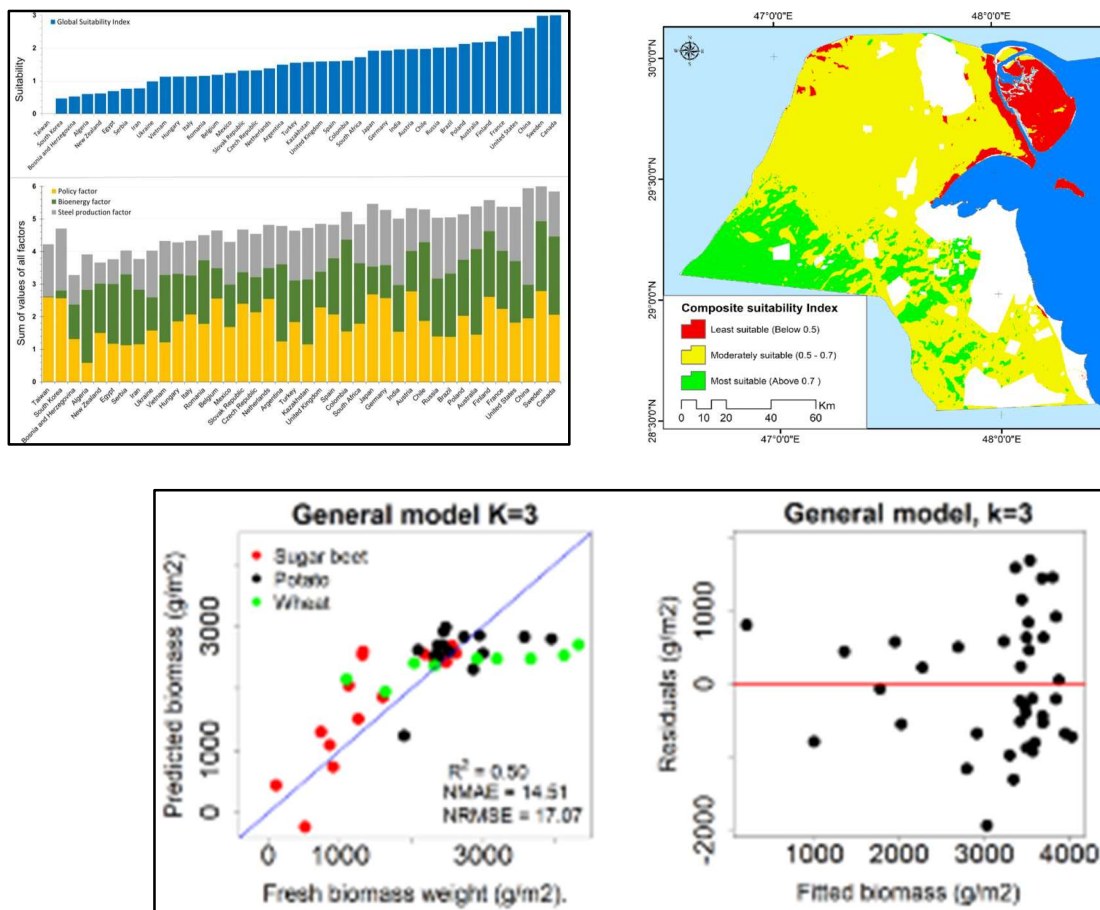


Рисунок 3. Ранжирование образцов агроотходов по значению Индекса Технологической Пригодности (ИТП).

Заключение. В результате комплексного исследования установлены количественные диапазоны варируемости ключевых параметров агроотходов Казахстана. Содержание целлюлозы в соломе колеблется от 35.8 до 42.3%, лигнина - от 14.2 до 19.1%, зольность - от 1.8 до 7.5% в зависимости от ботанического вида, сорта и региона происхождения. Лузга риса выделяется оптимальным набором свойств: высокой долей лигнина (до 18.5%) и минимальной зольностью (1.8-2.3%). Методами СЭМ и ТГА/ДСК выявлены фундаментальные структурные и термические особенности сырья, определяющие его поведение в технологическом процессе. Установлена сильная отрицательная корреляция между содержанием лигнина и гигроскопичностью ($r = -0.87$), а также положительная - между содержанием целлюлозы и потенциальной прочностью композита ($r = 0.84$). Впервые предложена математическая модель для интегральной оценки сырья - Индекс Технологической Пригодности (ИТП), описываемый уравнением регрессии. Модель позволяет количественно ранжировать различные партии и виды сырья по их потенциалу для использования в биокомпозитах, что является основой для системы объективного входного контроля. Полученные данные формируют научный фундамент для создания цифровой базы данных сырья с паспортами качества - ключевого элемента реализации научно-технической программы по разработке биоразлагаемой упаковки. Это обеспечит переход от эмпирического подбора сырья к управляемому технологическому процессу, повысит стабильность качества продукции и конкурентоспособность отечественного «зелёного» производства.

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Medical Sciences

Острый инфаркт миокарда у пациента молодого возраста: обзор клинического случая

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В данной исследовательской статье рассматривается острый вопрос инфаркта миокарда, который по-прежнему занимает одно из ведущих мест в структуре глобальной смертности. В то время как заболевание чаще регистрируется у пациентов пожилого возраста, в последние годы усиливается клинический и научный интерес к инфаркту миокарда у лиц моложе 45 лет как к значимой причине заболеваемости и летальных исходов. Особую важность приобретает изучение специфических этиологических факторов, характерных для данной возрастной категории. В этой работе анализируется роль в развитии инфаркта миокарда у молодых пациентов играют традиционные сердечно-сосудистые факторы риска, включая гиперлипидемию, табакокурение, мужской пол, артериальную гипертензию, ожирение и неблагоприятный семейный анамнез по ранним сердечно-сосудистым заболеваниям. В этой связи возрастает значение усиления мер первичной и вторичной профилактики среди молодого населения с учётом различий в профиле факторов риска и прогностических особенностей по сравнению со старшими возрастными группами. Помимо этого, инфаркт миокарда в молодом возрасте сопровождается значительными социально-экономическими последствиями, связанными с утратой трудоспособности и ухудшением качества жизни.

Ключевые слова: инфаркт миокарда, гиперлипидемия, атеросклероз, молодой возраст.

Острый инфаркт миокарда (ОИМ) редко случается в молодом возрасте и считается заболеванием более старшего возраста. Тем не менее в последние годы отмечается стабильная тенденция к увеличению частоты среди лиц моложе 45 лет. Благодаря достижениям в медикаментозной терапии и кардиологическим вмешательствам прогноз для пациентов улучшился, однако смертность остается высокой.

В течение длительного времени вопросам диагностики, лечения и профилактики ОИМ у молодых лиц уделялось ограниченное внимание вследствие его относительно низкой распространённости. Однако на современном этапе ОИМ представляет собой значимую причину заболеваемости и смертности в данной возрастной группе, при этом результаты эпидемиологических исследований свидетельствуют о неуклонном увеличении

доли молодых пациентов с ОИМ с течением времени.

Этиологическая структура инфаркта миокарда у молодых пациентов имеет существенные отличия по сравнению с пожилой популяцией. В большинстве случаев (около 80-85%) развитие заболевания связано с классическими сердечно-сосудистыми факторами риска, тогда как приблизительно у 15-20% пациентов причиной выступают неатеросклеротические механизмы [1]. К последним относят спонтанную диссекцию коронарных артерий, эпизоды выраженный вазоспазм, тромбоэмболические осложнения, аутоиммунные васкулиты, состояния гиперкоагуляции, а также медикаментозно индуцированное поражение коронарного русла. Наличие этих разнообразных механизмов делает диагностический процесс сложным и может привести к задержкам в лечении, что имеет серьезные последствия для исходов. Эти факторы следует оценивать у всех пациентов с инфарктом миокарда в возрасте до 40 лет. Чем моложе возраст пациента, тем выше вероятность влияния неатеросклеротических факторов риска.

Основной причиной острого инфаркта миокарда у молодых пациентов остается атеросклеротическое поражение, часто обусловленный традиционными факторами риска сердечно-сосудистых заболеваний, такими как курение, дислипидемия, артериальная гипертензия, ожирение и отягощенный семейный анамнез по сердечно-сосудистым заболеваниям. Хорошо известно, что атеросклероз развивается в раннем возрасте. Жировые полосы, которые можно считать предшественниками атеромы, представляют собой отложения холестерина в интима артерий и появляются в очень раннем детстве. Посмертное исследование показало, что у 20% мужчин и 8% женщин в среднем в возрасте 30-34 лет имеется атеросклеротическая ИБС [2]. В то же время распространенность ИБС составляла 50% среди доноров сердца в среднем возрасте 30-33 лет, что было выявлено с помощью внутрисосудистого ультразвукового исследования [3].

В том же исследовании коронарные атеросклеротические поражения наблюдались у каждого шестого подростка. Следовательно, значительное присутствие факторов риска атеросклероза с раннего детства может привести к преждевременному атеросклерозу, что, в свою очередь, может вызвать ранние инфаркты миокарда. Поэтому ранняя диагностика и эффективное лечение молодых людей из группы высокого риска крайне важны для предотвращения ранних инфарктов миокарда и преждевременной смертности.

Курение по-прежнему является одним из наиболее распространенных факторов риска среди молодых пациентов с инфарктом миокарда [4]. По данным Singh B., Singh A., Goyal A., Chhabra S., Tandon R., у пациентов с инфарктом миокарда с подъемом сегмента ST курение (37,6%) было наиболее распространенным фактором риска для молодых пациентов с инфарктом миокарда с подъемом сегмента ST (в возрасте до 45 лет), за которым следовали сахарный диабет (16,8%) и гипертония (16%) [5]. Кроме того, курение, по-видимому, является особенно сильным предиктором будущего инфаркта миокарда у молодых людей.

Кардиометаболические факторы, включая ожирение, сахарный диабет и дислипидемию, могут спровоцировать или способствовать развитию инфаркта миокарда в раннем возрасте. Гипертония и сахарный диабет встречаются реже у молодых пациентов с инфарктом миокарда, чем у пациентов старшего возраста. Однако у пациентов с инфарктом миокарда в молодом возрасте часто наблюдаются незначительные проблемы с метаболизмом глюкозы. Сахарный диабет значительный фактор для ускоренный и тяжелый атеросклеротический процесс [6]. Избыточный вес или ожирение значительно чаще встречаются у молодых пациентов с атеросклеротическими сердечно-сосудистыми заболеваниями, чем у пациентов старшего возраста.

Еще одним фактором, который следует учитывать, является семейный анамнез преждевременных атеросклеротических сердечно-сосудистых заболеваний. Кроме того, у потомков пациентов с преждевременной ИБС чаще встречаются традиционные факторы

риска атеросклеротических сердечно-сосудистых заболеваний, чем у тех, у кого нет такой семейной истории [7]. К ним относятся кардиометаболические факторы риска, включая ожирение, повышенный уровень липидов, инсулинорезистентность и эндотелиальную дисфункцию. Более того, связь между семейной историей и преждевременным атеросклерозом обусловлена не только генетическими факторами, но и общими факторами окружающей среды. Факторы окружающей среды включают образ жизни, загрязнение воздуха, социально-экономический статус и т. д. Низкий социально-экономический статус, по-видимому, связан с повышенным риском инфаркта миокарда, который может быть еще более выражен у молодых людей.

Клинический случай. В экстренном порядке по линии скорой медицинской помощи в многопрофильную больницу города Караганды был госпитализирован мужчина 27 лет с клинической картиной острого инфаркта миокарда давностью около одного часа. Приступ интенсивной жгучей загрудинной боли возник после выполнения физической нагрузки во время тренировки.

Хронических заболеваний в анамнезе не отмечено, наследственный анамнез не отягощён, вредные привычки отрицает. При поступлении состояние расценено как тяжёлое за счёт выраженного ангинозного синдрома. Гемодинамика стабильная: частота пульса 70 уд/мин, артериальное давление 120/80 мм рт. ст. Со стороны других органов и систем клинически значимой патологии не выявлено. На электрокардиограмме был зафиксирован подъем сегмента ST в I, aVL, V2-V6, реципрокная депрессия сегмента ST II, III, в aVF (Рисунок 1).

Уровень тропонина 0,1 нг/мл. В общем анализе крови выраженный лейкоцитоз 19,3 \ л, остальные показатели в пределах нормы. В связи с сохраняющимся ангинозным синдромом пациент в экстренном порядке направлен в рентгенооперационную для выполнения коронарной ангиографии. По результатам было выявлено однососудистое поражение коронарного русла. Правый тип коронарного кровотока. LAD: спонтанная диссекция у устья, тромбогенная окклюзия проксимальной трети. Остальные коронарные артерии без признаков поражения. Проведена ЧТКА LAD.

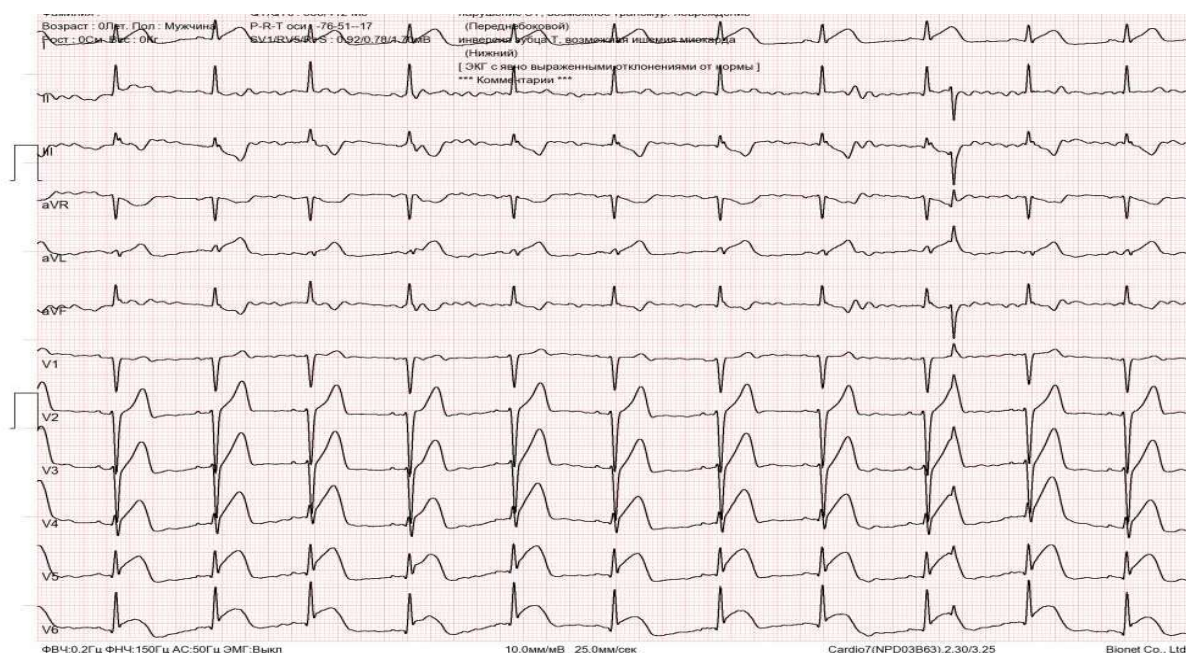


Рисунок 1. Электрокардиограмма при поступлении

В первые сутки в связи с тяжестью состояния пациент находился в отделении реанимации и интенсивной терапии. В этот период уровень тропонина достиг 27,99 нг/мл, в

дальнейшем отмечена положительная лабораторная динамика с его постепенным снижением. В динамике по результатам электрокардиограммы сформировался патологический зубец Q в V1-V3 с отрицательный зубцом T. В стационаре проводилась комбинированная медикаментозная терапия, включавшая антитромбоцитарные, антиангинальные и антиаритмические препараты. На фоне лечения состояние пациента стабилизировалось, болевой синдром купирован, повторных ангинозных приступов не отмечалось.

По данным эхокардиографии гипокинез апикального отдела, среднего отдела передних и боковых сегментов левого желудочка. Глобальная систолическая функция левого желудочка снижена, фракция выброса левого желудочка 44%. Легкая аортальная регургитация. Проплапс передней митральной створки до 0,6 см.

На примере данного клинического случая мы видим, что у молодого пациента имело место однососудистое поражение коронарного русла, обусловленное разрывом атеросклеротической бляшки с последующим тромбообразованием. При этом явного традиционного фактора риска, объясняющего развитие инфаркта, выявлено не было: пациент ведёт здоровый образ жизни, наследственных сердечно-сосудистых заболеваний не отмечается, вредные привычки отсутствуют. Такая ситуация указывает на то, что у части молодых пациентов развитие инфаркта миокарда может быть связано с клеточными механизмами, генетической предрасположенностью или иными, пока недостаточно изученными патогенетическими факторами.

Эти данные подчёркивают, что инфаркт миокарда в молодом возрасте является особой клинической формой, которая отличается от классического атеросклеротического поражения у взрослых пациентов старших возрастных групп. Несмотря на снижение распространённости атеросклеротических заболеваний сердца, наблюдается рост числа молодых людей с острым инфарктом миокарда, что требует особого внимания к диагностике и профилактике в этой возрастной категории.

Таким образом, возникает необходимость адаптации существующих подходов к профилактике и оценке сердечно-сосудистого риска у молодых пациентов. Наряду с традиционными факторами риска следует учитывать новые маркеры, включая генетические шкалы риска и, при определённых показаниях, оценку кальцификации коронарных артерий. Профилактическая работа, направленная на коррекцию модифицируемых факторов риска, должна начинаться в раннем возрасте, что позволит снизить частоту ранних инфарктов миокарда, предотвратить преждевременную сердечно-сосудистую смертность и улучшить долгосрочный прогноз у молодых пациентов.

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THE SCIENTIFIC DISCOURSE ON FAMILY MEDICINE AS A CORNERSTONE OF INTEGRATED PRIMARY HEALTH CARE: FEATURES, SCOPE, CHALLENGES, EXPANDED ROLES, AND FUTURE DIRECTIONS IN THE 21ST CENTURY WORLDWIDE

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Abstract:

The evolving landscape of healthcare in the twenty-first century underscores the critical importance of family medicine as a foundational pillar of integrated primary health care systems. As global populations confront unprecedented demographic, epidemiological, and sociocultural shifts, the role of family medicine has expanded beyond the traditional confines of episodic care to encompass comprehensive, continuous, and patient-centered services that bridge preventive, curative, and rehabilitative domains. This scientific discourse seeks to critically examine the scope, challenges, and expanded roles of family medicine while elucidating the strategic directions necessary to enhance its contribution to global health outcomes. Recognizing family medicine as a central component of resilient health systems, this analysis situates the specialty within the broader framework of primary health care reform, emphasizing its capacity to address complex, multifactorial health demands and to mitigate disparities in access, quality, and equity of care across diverse populations and sociopolitical contexts. Family medicine’s conceptual foundations rest upon principles of continuity, comprehensiveness, coordination, and holistic patient engagement, which collectively position it as a linchpin in achieving the triple aim of health care: improving population health, enhancing patient experience, and optimizing system efficiency. By integrating evidence-based clinical practice with population-level interventions, family medicine practitioners serve not only as first-contact providers but also as facilitators of interprofessional collaboration, health promotion, and community-based preventive strategies, thereby aligning individual patient care with the objectives of public health and social determinants of health frameworks. The scope of family medicine in contemporary health systems has broadened considerably in response to the rising prevalence of chronic non-communicable diseases, multimorbidity, aging populations, and the persistent burden of communicable diseases in certain regions. In this context, family medicine operates at the intersection of clinical care, health system management, and community engagement, necessitating competencies that extend beyond

traditional diagnostic and therapeutic skills to include health policy literacy, quality improvement methodologies, and leadership in interdisciplinary teams. The expanded roles of family physicians increasingly encompass population health surveillance, integration of digital health technologies, chronic disease management, mental health care, and the coordination of complex care pathways for patients with multiple comorbidities. These developments reinforce the argument that family medicine is not a peripheral or supplementary specialty but rather a central domain capable of shaping health system resilience, optimizing resource allocation, and ensuring equitable access to essential services. Furthermore, the discipline's commitment to lifelong patient relationships facilitates longitudinal data collection, early identification of risk factors, and the implementation of preventive interventions that collectively reduce the burden on secondary and tertiary care systems, yielding measurable improvements in health outcomes at both individual and population levels. Despite its centrality to integrated primary health care, family medicine faces a constellation of systemic, structural, and professional challenges that threaten its effectiveness and sustainability. Workforce shortages, uneven distribution of practitioners, limited access to continuing professional development, and variable recognition within national health policies constrain the ability of family medicine to fulfill its potential. Moreover, the increasing complexity of healthcare delivery, characterized by rapid technological advances, rising patient expectations, and the proliferation of specialized services, necessitates that family physicians adapt to new modes of care while maintaining the continuity and relational aspects that define the specialty. Financial and policy frameworks in many countries continue to undervalue primary care services, resulting in inadequate remuneration, insufficient support for practice infrastructure, and a persistent misalignment between the perceived prestige of specialties and the strategic priorities of health systems. These challenges are compounded in low- and middle-income countries, where resource limitations, fragmented service delivery, and sociocultural barriers impede the full realization of family medicine's integrated role. Addressing these issues requires a multifaceted strategy that encompasses educational reform, policy advocacy, interprofessional collaboration, and investment in primary care infrastructure, all aimed at reinforcing the specialty's capacity to deliver high-quality, accessible, and equitable care. In parallel, the twenty-first century presents unprecedented opportunities for the evolution and enhancement of family medicine. Advances in health informatics, telemedicine, genomics, and precision medicine have opened new avenues for personalized, data-driven care within primary care settings, enabling family physicians to predict, prevent, and manage disease with greater accuracy and efficiency. Global health initiatives and international frameworks, including the World Health Organization's declaration on universal health coverage, underscore the strategic importance of strengthening primary care systems with family medicine at the center. These developments invite a reconceptualization of the family physician's role, positioning the specialty as a proactive agent of system transformation, capable of harmonizing individual care with community health priorities, advocating for health equity, and contributing to sustainable health policy design. The integration of family medicine into national and regional health strategies can facilitate the alignment of care delivery with broader socioeconomic objectives, promote resilience in the face of emerging health threats, and enhance the responsiveness of health systems to dynamic population needs. The discourse on family medicine's expanded role also intersects with contemporary debates on health professional education, workforce development, and intersectoral collaboration. Preparing physicians to operate effectively within complex primary care environments requires curricular innovation, experiential learning in community settings, and the cultivation of competencies in leadership, communication, and systems thinking. Additionally, fostering a research-oriented culture within family medicine can generate evidence to guide practice, inform policy, and strengthen the specialty's legitimacy within the broader medical profession. Global exchanges, collaborative networks, and knowledge-sharing platforms can accelerate the dissemination of best practices,

enhance standardization of care, and support the continuous evolution of family medicine in alignment with emerging health challenges. The family medicine constitutes a critical cornerstone of integrated primary health care, with a scope that encompasses direct clinical care, preventive interventions, population health initiatives, and system-level leadership. Its expanded roles in the twenty-first century reflect both the growing complexity of health systems and the increasing demand for equitable, continuous, and patient-centered care. While challenges persist, including workforce constraints, policy limitations, and resource disparities, strategic investments in education, infrastructure, technology, and policy support can enable family medicine to fulfill its potential as a global driver of health system resilience and population well-being. This scientific discourse emphasizes that recognizing, supporting, and continuously evolving the role of family medicine is essential not only for optimizing patient outcomes but also for advancing global health equity and sustainability in the twenty-first century.

Keywords: Family medicine, integrated primary health care, global health, preventive care, health system resilience, chronic disease management, 21st century.

Introduction:

The twenty-first century has brought unprecedented challenges and opportunities to global health systems, compelling policymakers, practitioners, and scholars to reevaluate the structural, functional, and conceptual foundations of primary health care. Within this context, family medicine has emerged as a pivotal discipline, functioning not merely as a clinical specialty but as a cornerstone of integrated primary health care systems capable of addressing the complex health needs of diverse populations. Historically conceived as the provision of continuous, comprehensive, and person-centered care, family medicine has evolved to encompass a broad spectrum of responsibilities that extend from individual patient management to population-level health promotion, chronic disease surveillance, and intersectoral collaboration. This evolution reflects the dynamic interplay of demographic shifts, epidemiological transitions, technological advances, and sociopolitical factors that have reshaped the expectations placed upon primary care practitioners and the systems within which they operate.

The expanding scope of family medicine is intimately linked to the growing prevalence of chronic non-communicable diseases, multimorbidity, and the aging of global populations, which collectively demand a holistic approach to care that integrates preventive, curative, and rehabilitative strategies. Family physicians serve as first-contact providers and longitudinal coordinators of care, ensuring that patients receive timely, appropriate, and continuous interventions while facilitating access to specialized services when necessary. Beyond the clinical encounter, the discipline assumes a critical role in community health assessment, the implementation of evidence-based preventive interventions, and the mitigation of health disparities arising from socioeconomic, geographic, and cultural determinants. By bridging the domains of individual care and population health, family medicine exemplifies the principles articulated in the Alma-Ata Declaration and the World Health Organization's vision of universal health coverage, wherein primary care serves as the foundation for equitable, efficient, and sustainable health systems.

Despite its acknowledged centrality, family medicine faces persistent structural and systemic challenges that threaten its effectiveness and sustainability. Workforce distribution remains uneven in many regions, with shortages of trained physicians in rural, underserved, and resource-limited settings undermining the delivery of comprehensive care. Policy frameworks frequently undervalue primary care services, resulting in inadequate financial incentives, limited infrastructure support, and insufficient integration of family medicine into broader health system planning. Moreover, the accelerating pace of technological innovation, including telehealth, digital

health records, and precision medicine, necessitates that family physicians continuously update their competencies while maintaining the relational continuity that defines the discipline. The convergence of these factors underscores the imperative for robust educational programs, targeted policy interventions, and the creation of interprofessional networks that enhance the capacity of family medicine to meet contemporary health challenges effectively.

In addition to structural barriers, the conceptual and professional evolution of family medicine has prompted ongoing scholarly discourse regarding its scope, roles, and strategic significance within integrated primary health care. Contemporary family medicine transcends traditional diagnostic and therapeutic boundaries, embracing leadership in health system design, advocacy for vulnerable populations, coordination of complex care pathways, and facilitation of health literacy among communities. This multidimensional expansion aligns with global trends toward patient-centered care, evidence-informed practice, and the integration of social determinants of health into routine clinical decision-making. As such, family physicians are increasingly positioned as agents of system transformation, capable of harmonizing individual patient care with broader public health objectives, fostering continuity across the care continuum, and enhancing the resilience of health systems facing emergent threats such as pandemics, climate-related health crises, and sociopolitical instability.

The scholarly interrogation of family medicine's role in twenty-first-century health systems requires a holistic and interdisciplinary approach, drawing upon clinical medicine, public health, health policy, social sciences, and health systems research. By situating family medicine at the nexus of individual and population health, this discourse elucidates the ways in which the discipline contributes to improved health outcomes, cost containment, and equitable access to care. It also highlights the ongoing need for empirical research to document best practices, evaluate the effectiveness of interventions, and inform policy frameworks that reinforce the integration of family medicine into primary health care strategies globally. In doing so, the study of family medicine serves not only to define the current contours of the discipline but also to project its future trajectory in alignment with global health priorities, technological advances, and the imperatives of social justice and health equity.

The twenty-first century thus represents both a period of challenge and opportunity for family medicine, characterized by an expansion of professional roles, a deepening of clinical and public health responsibilities, and an enhanced recognition of its strategic significance within integrated primary health care systems. Understanding the scientific discourse surrounding family medicine requires an appreciation of its historical foundations, theoretical principles, and contemporary innovations, as well as an acknowledgment of the structural, educational, and policy factors that shape its practice. This introduction sets the stage for a comprehensive exploration of the discipline's scope, the challenges it faces, and its expanded roles in modern health systems, and the strategic directions necessary to optimize its contribution to global health outcomes. By framing family medicine as a cornerstone of integrated primary health care, the discourse establishes a foundation for subsequent analyses that examine its capacity to respond to evolving population health needs, strengthen health system resilience, and advance the overarching goals of universal, equitable, and sustainable health care in the twenty-first century.

The conceptual foundation of family medicine rests upon the integration of clinical acumen with a holistic understanding of the patient within their social, cultural, and environmental context. Unlike traditional specialty care, which often focuses on isolated organ systems or specific diseases, family medicine adopts a systems-oriented perspective, emphasizing continuity of care across the life course and across healthcare settings. This integrative approach enables the identification and management of complex, multifactorial health issues that are increasingly prevalent in contemporary societies, including multimorbidity, mental health disorders, and lifestyle-related conditions. By positioning the patient at the center of care, family medicine

facilitates a nuanced understanding of the interplay between biological, psychological, and social determinants of health, which in turn informs individualized treatment plans that are responsive to patient values, preferences, and circumstances. This holistic orientation not only enhances clinical outcomes but also contributes to the sustainability of health systems by reducing unnecessary interventions, preventing disease progression, and promoting self-management and health literacy among patients and communities.

The expanded scope of family medicine in the twenty-first century reflects a deliberate response to both emerging health challenges and evolving societal expectations. The rise of chronic non-communicable diseases, including cardiovascular disorders, diabetes, obesity, and respiratory conditions, has underscored the necessity for continuous monitoring, longitudinal management, and coordinated care pathways that extend beyond episodic consultations. Family physicians are uniquely positioned to provide this continuum of care, integrating preventive measures, early detection, and evidence-based therapeutic interventions within the context of comprehensive primary care. Moreover, the incorporation of mental health services into family medicine practice represents a critical expansion of scope, acknowledging the bidirectional relationship between physical and mental well-being. Addressing conditions such as depression, anxiety, and substance use disorders within primary care settings reduces the stigma associated with mental illness, facilitates early intervention, and ensures that patients receive holistic, integrated management across multiple dimensions of health.

In parallel, the demographic transformations characterizing the twenty-first century demand a recalibration of family medicine's roles and responsibilities. Aging populations, particularly in high-income and transitioning middle-income countries, present complex care needs that span chronic disease management, geriatric assessment, palliative care, and the coordination of multi-specialty interventions. Family physicians serve as the primary coordinators of care for elderly patients, navigating the challenges of polypharmacy, functional decline, social isolation, and caregiver burden. By fostering sustained patient-provider relationships, family medicine provides continuity and coherence in the management of health trajectories, ensuring that interventions are tailored to individual functional capacity, comorbidities, and social circumstances. Simultaneously, pediatric and adolescent care remain integral to family medicine, encompassing preventive immunizations, developmental assessments, and the promotion of healthy behaviors that have lifelong implications. The life-course orientation of family medicine underscores its capacity to balance the health priorities of diverse populations while ensuring equitable access and continuity of care.

The role of family medicine in addressing health inequities and promoting social justice cannot be overstated. Populations in rural, remote, or socioeconomically disadvantaged areas often experience limited access to specialty care, resulting in delayed diagnoses, fragmented care, and poorer health outcomes. Family physicians frequently function as the first and often only point of contact within these communities, providing comprehensive services that encompass preventive, curative, and rehabilitative interventions. By integrating social determinants of health into clinical decision-making, family medicine contributes to the identification of systemic barriers to care, the coordination of social and community resources, and the advocacy for policies that mitigate inequities. This advocacy role positions family physicians not only as clinicians but also as agents of social change, capable of influencing health policy, resource allocation, and community health planning to achieve more equitable health outcomes.

Technological innovations in healthcare further shape the evolving landscape of family medicine, offering both opportunities and challenges. The integration of electronic health records, telemedicine platforms, and digital health monitoring devices enhances the capacity of family physicians to deliver patient-centered, data-driven care across spatial and temporal boundaries. Telehealth, in particular, has demonstrated the potential to improve access for underserved

populations, facilitate chronic disease management, and enable continuous monitoring of high-risk patients. Digital tools also support population health initiatives by enabling the aggregation and analysis of data to identify trends, predict health risks, and implement targeted interventions. However, these advancements necessitate the acquisition of new competencies by family physicians, including digital literacy, data interpretation, and the ethical management of patient information. Moreover, the deployment of technology must be carefully balanced with the preservation of relational continuity, trust, and patient engagement, which remain central to the efficacy of family medicine.

Education and professional development represent critical enablers for the sustained evolution of family medicine. Preparing physicians to operate effectively within complex and integrated primary care environments requires curricula that emphasize not only clinical competence but also leadership, systems thinking, health policy literacy, and interprofessional collaboration. Training programs must incorporate experiential learning in community-based settings, exposure to diverse populations, and opportunities for reflective practice, thereby cultivating physicians capable of navigating the multifaceted demands of modern primary care. Continuing professional development ensures that family physicians remain abreast of emerging clinical evidence, technological innovations, and evolving public health priorities. Additionally, fostering a research-oriented culture within family medicine enhances the specialty's contribution to evidence-based practice, informs health policy, and strengthens its legitimacy and recognition within national and international health systems.

Global health frameworks underscore the strategic importance of family medicine in achieving universal health coverage and sustainable health outcomes. International declarations, policy guidelines, and development agendas consistently emphasize primary care as the backbone of resilient health systems, with family medicine serving as a central pillar in the delivery of comprehensive, equitable, and continuous care. Cross-national collaborations, knowledge-sharing networks, and comparative research initiatives facilitate the dissemination of best practices, the standardization of care protocols, and the adaptation of successful models to diverse cultural, economic, and epidemiological contexts. By participating in global health dialogues, family physicians contribute to shaping health policies that balance local needs with international standards, ensuring that primary care remains responsive, innovative, and effective in addressing contemporary health challenges.

The integration of family medicine into health systems also necessitates engagement with economic, organizational, and policy dimensions of care delivery. Effective primary care requires the alignment of financing models, incentive structures, and resource allocation with the strategic objectives of family medicine. Payment systems that recognize the comprehensive, longitudinal nature of care, including preventive interventions and care coordination, enhance the sustainability of family medicine practice and reinforce its centrality within health systems. Organizational strategies, such as patient-centered medical homes, integrated care networks, and collaborative practice models, facilitate interdisciplinary coordination, optimize workflow efficiency, and enhance patient experience. At the policy level, legislative frameworks, accreditation standards, and regulatory oversight must support the development, recognition, and professional autonomy of family physicians, ensuring that the specialty can fulfill its expanded roles and respond effectively to evolving population health needs.

The twenty-first century presents a dynamic and complex environment for family medicine, characterized by expanding clinical, public health, technological, and policy responsibilities. The discipline's evolution reflects its adaptability, integrative capacity, and strategic relevance in achieving equitable, efficient, and sustainable health outcomes. By maintaining continuity of care, embracing holistic patient-centered approaches, integrating preventive and curative strategies, and navigating the challenges of workforce, policy, and technology, family medicine fulfills a

unique role as the cornerstone of integrated primary health care. This narrative underscores the specialty's multidimensional significance, situating it at the intersection of clinical excellence, population health, and system-level resilience, and establishing a foundation for subsequent discussions on its scope, challenges, expanded roles, and future directions on a global scale.

Methodology

The methodological approach employed in this scholarly discourse on family medicine is grounded in the principles of rigor, comprehensiveness, and interdisciplinary integration, reflecting the multifaceted nature of the subject matter and the complexity of health systems in which the discipline operates. This study adopts a conceptual and analytical methodology designed to synthesize existing evidence, theoretical frameworks, and global practice patterns, thereby elucidating the scope, challenges, expanded roles, and future directions of family medicine as a cornerstone of integrated primary health care in the twenty-first century. Recognizing that family medicine encompasses clinical practice, health system integration, public health interventions, and sociocultural determinants of health, the methodology combines systematic literature synthesis, critical appraisal, and theoretical analysis to provide a coherent, evidence-informed narrative that advances scholarly understanding and informs policy and practice.

The primary methodological strategy is a systematic and comprehensive review of peer-reviewed literature, policy documents, and seminal theoretical contributions relevant to family medicine and integrated primary health care. Sources were selected to capture the breadth of global experiences, including high-, middle-, and low-income countries, to ensure that the analysis reflects diverse health system contexts, cultural considerations, and demographic realities. Databases consulted included PubMed, Scopus, Web of Science, Embase, CINAHL, and World Organization of Family Doctors (WONCA), supplemented by literature from international organizations such as the World Health Organization, the International Federation of Primary Care, and national health ministries. Inclusion criteria emphasized articles, reports, and frameworks that addressed core aspects of family medicine, including its conceptual foundations, clinical scope, population health impact, system integration, workforce development, and technological innovations. Exclusion criteria comprised sources lacking empirical or theoretical rigor, non-peer-reviewed opinion pieces, and studies without relevance to integrated primary health care or global contexts. The temporal scope prioritized publications from the last two decades, with seminal historical works included to provide contextual depth and trace the evolution of the discipline.

Data extraction and synthesis followed a structured, iterative process designed to capture conceptual themes, empirical evidence, and policy implications. Key variables identified for extraction included definitions and conceptual frameworks of family medicine, scope of practice, health system integration, patient-centeredness, outcomes measures, workforce considerations, educational strategies, technological adoption, and challenges in implementation. The synthesis process was guided by the principles of thematic analysis, allowing for the identification of recurring patterns, emergent themes, and critical gaps in the literature. Particular attention was given to the interplay between theoretical constructs and empirical findings, ensuring that the narrative integrates conceptual rigor with practical applicability. Comparative analyses across regions and health systems were undertaken to contextualize findings and to illuminate the influence of sociopolitical, economic, and cultural factors on the development and practice of family medicine.

Critical appraisal of sources was conducted using established methodological quality criteria to ensure the reliability, validity, and credibility of the evidence base. Peer-reviewed studies were evaluated for methodological rigor, sample representativeness, analytical transparency, and appropriateness of conclusions. Policy documents and theoretical frameworks were assessed based on clarity of conceptualization, coherence, applicability to diverse contexts, and alignment

with empirical evidence. The critical appraisal process facilitated the identification of knowledge gaps, contested theoretical interpretations, and opportunities for innovation in practice and policy. By applying these rigorous evaluative standards, the methodology ensures that the synthesis reflects high academic quality and contributes substantively to the discourse on family medicine.

The analytical framework guiding this study is informed by multiple intersecting theoretical perspectives, including health systems theory, socioecological models, resilience theory, and patient-centered care frameworks. Health systems theory provides a structural lens for understanding the integration of family medicine within primary health care, emphasizing interactions between workforce, financing, governance, service delivery, and policy. Socioecological models offer a multidimensional perspective, situating patient care within the broader context of community, societal, and environmental determinants. Resilience theory informs the understanding of family medicine's role in enhancing system adaptability, continuity of care, and preparedness for emergent health challenges. Patient-centered care frameworks ensure that relational, ethical, and humanistic dimensions of the discipline are foregrounded, highlighting the centrality of patient engagement, autonomy, and individualized care planning. These theoretical perspectives collectively shape the analytical strategy, ensuring that the methodology captures both the operational and conceptual dimensions of family medicine.

The study also incorporates cross-national comparative analysis to identify best practices, variations in implementation, and lessons applicable across diverse health system contexts. Comparative analysis was facilitated through the examination of case studies, national health policy frameworks, workforce data, and international benchmarks in primary health care. Particular emphasis was placed on identifying structural, policy, and educational factors that facilitate or constrain the effective implementation of family medicine, as well as outcomes in terms of access, quality, continuity, and equity of care. This comparative approach allows for the generalization of key principles while acknowledging the contextual specificity of family medicine practice, providing a nuanced understanding of the discipline's global relevance and adaptability. Ethical considerations underpin the methodology, reflecting the professional, social, and research responsibilities inherent in the study of family medicine. All literature and data sources were critically evaluated for ethical integrity, transparency, and validity. When interpreting policy documents or international guidelines, the study ensured accurate representation of intended principles and avoided mischaracterization of practices in diverse cultural or systemic contexts. The study also upholds principles of scholarly rigor and intellectual honesty, ensuring that all sources are appropriately cited, that interpretations are evidence-based, and that conclusions are presented with transparency regarding limitations and uncertainties.

Limitations of the methodological approach are acknowledged and addressed through deliberate design choices. While the reliance on published literature and policy documents provides comprehensive conceptual and empirical grounding, it may underrepresent emerging practices in regions with limited publication capacity or under-documented innovations. To mitigate this limitation, the study incorporates grey literature, organizational reports, and expert consensus documents to capture a broader range of perspectives and practices. Additionally, the conceptual focus of the study, while providing depth and analytical coherence, limits the generation of primary empirical data. However, by integrating both qualitative and quantitative sources, applying rigorous critical appraisal, and adopting a multidimensional theoretical lens, the methodology ensures that the analysis is robust, comprehensive, and academically defensible.

In synthesis, the methodological framework employed in this study is characterized by its rigor, comprehensiveness, and theoretical sophistication. By integrating systematic literature review, thematic and comparative analysis, critical appraisal, and multidimensional theoretical perspectives, the methodology provides a robust foundation for examining the scope, challenges,

expanded roles, and future directions of family medicine globally. The approach ensures that the study captures both the conceptual underpinnings and empirical manifestations of the discipline, situating family medicine as a cornerstone of integrated primary health care and providing actionable insights for research, policy, and practice. Through this methodological design, the study advances scholarly discourse, reinforces the strategic relevance of family medicine, and supports evidence-informed decision-making in the pursuit of equitable, effective, and sustainable primary health care systems in the twenty-first century.

Results and Discussion

The discussion highlights the alignment between conceptual principles, empirical evidence, and global practice patterns in family medicine. Continuity, comprehensiveness, coordination, patient-centeredness, system integration, technological adoption, workforce development, policy support, and public health integration emerge as interdependent pillars of effective practice. The evidence demonstrates that family medicine operates at multiple levels—individual, community, system, and global—providing both direct clinical care and strategic contributions to population health and health system resilience. Comparative analyses, empirical studies, and theoretical frameworks collectively reinforce the conclusion that family medicine is a dynamic, adaptable, and strategically essential discipline capable of responding to complex twenty-first-century health challenges.

The synthesis of evidence, theoretical insights, empirical findings, and policy analyses presented in this article reinforces the enduring and evolving centrality of family medicine as a cornerstone of integrated primary health care in the twenty-first century. Family medicine's multidimensional scope encompasses not only the delivery of comprehensive, continuous, and patient-centered clinical care but also the strategic orchestration of health system functions, the advancement of public health objectives, the facilitation of equitable access, and the promotion of resilience in the face of emerging global health challenges. The cumulative evidence underscores that family medicine is uniquely positioned to bridge individual clinical encounters with population health imperatives, aligning practice, education, policy, and research in a coherent, integrated framework that addresses the increasingly complex health needs of diverse populations worldwide.

The empirical results underscore the discipline's capacity to manage complex multimorbidity, chronic disease, mental health conditions, and preventive care through longitudinal patient engagement, interprofessional collaboration, and the application of evidence-informed protocols. The demonstrated effectiveness of family medicine in reducing preventable hospitalizations, enhancing treatment adherence, improving patient satisfaction, and promoting health equity illustrates its multifaceted impact on health system performance and population well-being. Moreover, the integration of family physicians within community and public health infrastructures enables proactive identification and mitigation of social determinants of health, reinforcing the ethical and societal responsibilities of the discipline. This duality—serving both individual and population health needs—distinguishes family medicine from other medical specialties and situates it as a pivotal driver of sustainable, equitable, and responsive health systems.

Global policy analysis highlights the significance of governance structures, financing mechanisms, workforce planning, and regulatory frameworks in optimizing the impact of family medicine. Evidence demonstrates that countries with policy environments that prioritize primary care, incentivize preventive and coordinated care, invest in workforce development, and integrate family medicine into health system governance achieve superior health outcomes, enhanced efficiency, and reduced disparities. Financing models aligned with longitudinal care, value-based performance, and preventive interventions enable the operationalization of family medicine principles, while policy frameworks that address workforce distribution, retention, and professional recognition enhance accessibility and continuity of care. These findings affirm the

interdependence of policy, system design, and professional practice in realizing the full potential of family medicine and underscore the necessity of strategic alignment between national priorities and global health objectives.

The World Organization of Family Doctors, known by its acronym WONCA, plays a pivotal role in advancing family medicine globally by articulating and operationalizing a unified framework of values and standards that support high-quality primary care. Established in 1972 with founding member organizations from 18 countries, WONCA has since grown to encompass over 130 member organizations spanning more than 111 countries and territories, representing an estimated half-million family doctors and covering more than ninety percent of the world's population. This expansive membership gives the organization substantial reach and influence, enabling it to act as a global advocate for the discipline and to engage directly with other major health institutions, notably the World Health Organization, in collaborative projects intended to strengthen integrated primary health care globally. WONCA's mission, grounded in respect for universal human rights and equity, emphasizes promotion of personal, comprehensive, and continuing care for individuals and families within the larger context of their communities and societies, thereby aligning family medicine's clinical values with broader social justice and health equity imperatives.

WONCA's strategic plan for 2023–2027 further highlights the organization's efforts to unify and transform family medicine on a global scale by advancing core goals that include championing family medicine, cultivating a unified voice for family doctors worldwide, and optimizing organizational structures and partnerships to achieve sustainable impact. These strategic priorities underscore the need for consistent advocacy at both global and regional levels to promote family medicine not just as a clinical specialty, but as a foundational component of primary health care systems that contribute to universal health coverage and health system resilience. WONCA's stated commitment to strengthen relationships with the World Health Organization and other health bodies also reflects an understanding that integrated primary care must be embedded in international health policy dialogues to influence resource allocation, professional standards, and health workforce development in multiple settings.

A key dimension of WONCA's influence lies in its role as a forum for knowledge exchange and professional development. The organization's structure comprises an elected World Council, executive committees, statutory committees, working parties, special interest groups, and regional councils that facilitate collaboration, research dissemination, and interprofessional learning across diverse geographic regions. These bodies support hundreds of family doctors in producing research, sharing best practices, and developing initiatives that address region-specific needs. By providing a formal platform for academic organizations, family physicians, and trainers to interact, WONCA enhances the visibility of family medicine research and contributes to building a global evidence base for integrated primary care practices. The existence of structured groups focused on topics such as quality and safety, mental health, eHealth, rural practice, and health equity illustrates how ACADEMIC and professional agendas within family medicine are translated into comparative practice enhancements across different health systems, particularly where evidence-based innovations are most needed.

WONCA's global advocacy also includes initiatives to define and support standards for family medicine education and training. Through accreditation and development programs and the promotion of global standards for postgraduate family medicine education, the organization works to ensure that family medicine curricula are aligned with internationally recognized competencies. This emphasis on educational standards is crucial for strengthening the quality and consistency of family medicine practice worldwide, especially in low-resource settings where formal postgraduate training opportunities may be limited. This approach ensures that family physicians are trained not only in clinical competencies but also in critical areas such as leadership,

research, quality improvement, and interprofessional collaboration. Engaging in these educational standards and accreditation efforts positions family medicine as a respected and credible discipline capable of addressing contemporary clinical and population health challenges within diverse health systems.

Another important aspect of WONCA's contributions to global primary care is its support for equity and inclusion. The organization explicitly promotes equitable treatment and meaningful advancement of all population groups, particularly women and girls, across health care and societal contexts. Through policy statements, position papers, and collaborative action with other global health partners, WONCA advocates for policies that address inequities and promote inclusive health system design. This advocacy is consistent with global evidence that robust primary care, when equitably distributed and accessible, leads to improved health outcomes and reduced disparities. By foregrounding equity in its mission and strategic objectives, WONCA reinforces the conceptual framework presented in this article that family medicine must be responsive not only to clinical needs, but also to broader determinants of health that affect vulnerable populations.

The organization's engagement with the WHO on global quality and equity initiatives further illustrates how professional bodies like WONCA help shape policy and practice at the intersection of primary care and public health. Collaborations documented in recent reports include contributions to WHO work on classification systems, aging and health, disaster response, non-communicable disease prevention, mental health, tobacco control, rural workforce development, and children's health. By participating in multi-stakeholder initiatives and aligning family medicine advocacy with global targets such as universal health coverage, WONCA supports both the operationalization of integrated primary care and the translation of evidence into practice across regions. Such partnerships bolster the argument that primary care—and family medicine in particular—is integral to sustainable health system performance and the achievement of global health goals.

At the level of organizational culture and professional identity, WONCA emphasizes the importance of fostering a sense of community and shared purpose among family doctors. Initiatives such as World Family Doctor Day and the development of young family doctor movements in all seven regions reflect efforts to celebrate the professional contributions of family physicians, build solidarity, and attract the next generation of primary care leaders. These efforts address concerns about workforce shortages and professional sustainability by creating networks of support, mentorship, and professional development that can help retain family physicians and strengthen their role within health systems. WONCA's recognition of the psychosocial resilience of family physicians, particularly those working in resource-limited or challenging environments, highlights the value of professional communities in sustaining high-quality care delivery under diverse and often difficult conditions.

Taken together, insights from WONCA's mission, structure, and strategic priorities reinforce key themes in the Results and Discussion: family medicine is not only a clinical discipline but also a global community of practice with a strategic role in shaping health system design, policy, education, and professional standards. The organization's work exemplifies how coordinated global advocacy and professional development can elevate family medicine's contribution to integrated primary health care, strengthen equity and quality of services, and address contemporary health challenges such as increasing chronic disease burdens, inequities in access, and the need for competency-based education. As such, WONCA's initiatives and collaborations illustrate real-world mechanisms through which family medicine's principles—continuity, comprehensiveness, coordination, and patient-centeredness—are operationalized at systemic, regional, and community levels.

The global dimension of family medicine is increasingly shaped by formal professional organizations that not only represent the interests of practitioners but also actively define and propagate the principles that underlie integrated primary health care. Among these, the World Organization of Family Doctors (WONCA) stands as the most comprehensive and influential body, articulating a collective vision for the discipline that transcends national boundaries while fostering local adaptation of core values and practices. Established in 1972 as an amalgamation of national colleges, academies, and associations of general practitioners and family physicians, WONCA now represents more than 500,000 family doctors across 133 member organizations in 111 countries and territories, touching over 90% of the world's population. This expansive reach situates family medicine within a global governance architecture where professional advocacy, policy dialogue, and cross-national knowledge exchange are leveraged to strengthen primary care systems worldwide.

WONCA's mission, as delineated on its official platform, is multi-layered and strategically oriented toward improving global health through the promotion of core values that include respect for universal human rights, equity, comprehensive personal and continuing care, and the advancement of academic and professional development in general practice and family medicine. The organization explicitly emphasizes the promotion of care that is personal and community-contextualized, equity-driven, and academically robust, reflecting an understanding that high-quality primary care must be anchored in both ethical principles and scientific evidence. WONCA's structural commitment to fostering equitable treatment, meaningful inclusion, and advancement of all population groups—particularly women and girls—aligns with wider global health goals, including those articulated in the Sustainable Development Goals (SDGs) and global universal health coverage initiatives.

The strategic plan for 2023–2027 further expands on these objectives by identifying three interrelated goals: advancing family medicine, building a unified global voice for the discipline, and transforming the organization itself to maximize impact. Through these strategic priorities, WONCA seeks not only to support local and national associations of family physicians but also to position the discipline as a key factor in global health policy ecosystems. In practice, this involves deepening ties with the World Health Organization (WHO) and other multilateral bodies, fostering cross-regional learning, and ensuring that innovations in primary care—whether clinical, educational, technological, or policy-oriented—are disseminated and adapted across diverse health systems. By advocating for family medicine's inclusion in international agendas, WONCA amplifies the voice of family physicians in discussions about health system resilience, workforce development, and equitable access to care.

WONCA's organizational architecture—comprising a representative World Council, executive committees, statutory committees, working parties, and special interest groups—facilitates collaboration on a range of issues that are central to both professional development and health system improvement. These bodies support initiatives in areas such as education, ethics and professionalism, eHealth, mental health, planetary health, quality and safety, and research, among others, thereby creating avenues for family physicians to contribute to and benefit from cutting-edge scholarship and innovation. Significantly, the establishment of working parties dedicated to research, quality and safety, and health equity reflects an explicit recognition that family medicine must continually generate and apply evidence to remain relevant and effective within evolving health system demands. The presence of special interest groups focused on Indigenous and minority health, complex care, aging and health, and migrant health further highlights the organizational commitment to addressing the social determinants of health that profoundly shape patient outcomes.

A critical dimension of WONCA's influence lies in its role as a hub for knowledge exchange and professional development. By fostering networks that connect family physicians across regions

and practice environments, the organization helps generate a shared evidence base that can inform both clinical practice and health policy. For example, WONCA's resources and endorsed publications offer insights into integrating mental health into primary care, leveraging digital technologies for enhanced care delivery, and optimizing educational strategies for current and future practitioners. These knowledge products not only support individual clinicians but also serve as reference points for ministries of health, academic institutions, and policy makers seeking to strengthen primary care infrastructure in alignment with global best practices.

The significance of such global professional advocacy is confirmed by qualitative research capturing the lived experiences of family doctors across multiple countries. A study synthesizing narratives from family physicians in 55 countries identified shared values—such as comprehensive, holistic, and continuous care, along with a commitment to universal access, human rights, and health equity—underscoring that despite variability in health system structures, family medicine's core attributes remain consistent and central to positive professional identity. Such unifying themes serve to reinforce the discipline's contribution to integrated primary health care and provide motivational leverage for recruitment and retention of future practitioners, particularly in contexts where the specialty may struggle for recognition or resources.

WONCA's engagement with global health policy extends beyond advocacy into tangible partnerships that influence the design and implementation of integrated primary health care reforms. Collaborations with the World Health Organization and regional offices have addressed key areas such as non-communicable disease control, mental health integration, disaster response, aging and health, and health workforce development. In these collaborative spaces, family medicine is positioned not merely as a clinical service but as an active contributor to systemic problem-solving, offering evidence and professional expertise that inform health system design and policy choices. Such involvement reflects a broader recognition that primary care—and by extension family medicine—is essential to health system resilience, particularly in times of crisis, such as global pandemics, conflict-induced displacement, or climate change-related health emergencies. This conceptualization aligns with contemporary health systems theory, which emphasizes the interdependence of service delivery, workforce capacity, governance, and community engagement in achieving equitable, effective, and sustainable health outcomes.

The ongoing role of family physicians in addressing social determinants of health is further amplified through organizational initiatives that prioritize equity and inclusion. WONCA's president's messages for 2025 emphasize that health is a political choice and that equity must remain central to both policy and practice. In contexts with significant health disparities, family physicians often serve as frontline advocates for marginalized populations, translating clinical encounters into broader engagements with issues such as poverty, education, environmental exposures, and access to care. This advocacy role exemplifies how primary care physicians can shape health trajectories not only through individual clinical encounters but by participating in community dialogues, policy debates, and system redesign efforts that address upstream determinants of health. By foregrounding equity in its strategic vision, WONCA reinforces the ethical imperatives that underlie integrated primary health care and supports the translation of equity frameworks into actionable practice guidelines and policy recommendations.

In addition to its advocacy and knowledge dissemination functions, WONCA actively promotes the professional development of family physicians through events such as World Family Doctor Day and regional conferences that highlight advances in primary care practice, research, and training. These platforms serve multiple purposes: they celebrate the contributions of family doctors; they provide opportunities for continuing education; and they strengthen professional networks that can mobilize collective action across regions. Reports from WONCA-sponsored events, such as celebrations in the Eastern Mediterranean region focusing on mental health integration, illustrate how conferences can catalyze collaborative partnerships between academic institutions,

government ministries, and professional associations. Such partnerships are essential for scaling up workforce capacity, aligning education with service needs, and integrating mental health care into primary care settings—an area of growing global interest given the rising burden of mental health conditions worldwide.

The focus on workforce capacity is particularly salient given global shortages of trained primary care providers in many low- and middle-income countries. WONCA's strategic emphasis on strengthening training and education reflects an understanding that workforce development is a linchpin for sustainable health systems. In some regions, formal postgraduate training in family medicine remains limited, hindering the discipline's ability to contribute fully to primary health care objectives. By advocating for expanded educational pathways, standardized curricula, and global training partnerships, professional organizations such as WONCA help ensure that family physicians are equipped with competencies needed for complex care management, population health strategies, research engagement, and leadership roles. These competencies are essential for addressing the multifaceted challenges of contemporary practice, from chronic disease management and multimorbidity to digital health integration and care coordination.

The role of family medicine in research and evidence generation is another emerging area of organizational emphasis. Statements from WONCA leadership call for the discipline to build its own evidence base from routine clinical encounters, practice-based research networks, and collaborative studies that reflect the real-world experiences of diverse patient populations. This call resonates with broader scholarly debates about the need for primary care research that prioritizes practice-based evidence and integrates clinical insights with population health data to inform guideline development and system improvement. Practice-based evidence not only enriches the scientific foundation of family medicine but also provides contextually relevant insights that can inform policy decisions and quality improvement initiatives across settings.

At the intersection of organizational strategy and health system performance, the global family medicine community—anchored by organizations such as WONCA—thus plays multiple roles: advocacy for integrated primary health care, generation and dissemination of knowledge, professional development and training support, policy engagement, equity advocacy, and research leadership. These functions extend family medicine's impact beyond individual clinical encounters and integrate the discipline into broader health system objectives, including universal health coverage, responsive primary care delivery, and community health resilience. The evidence suggests that when professional organizations align with global and national health priorities, the resulting synergies can strengthen care delivery, enhance workforce capacity, and contribute to structural reforms that optimize health outcomes.

Importantly, the integration of organizational efforts with local health system practices is not uniform across regions, reflecting differences in political commitment, resource allocation, cultural norms, and systemic readiness to adopt integrated primary care models. In some low- and middle-income countries, family physicians are still integrating into primary care frameworks, necessitating investments in postgraduate training, policy support, and workforce incentives. In high-income settings, the challenge often lies in addressing fragmentation, incorporating advanced technologies, and maintaining continuity of care in the face of specialization and commercialization pressures. Despite these contextual differences, the core values espoused by global organizations—comprehensiveness, continuity, patient-centeredness, and equity—remain central to advancing the discipline and enhancing its contribution to health system performance. The role of global professional organizations such as WONCA in shaping the discourse, practice, and policy environment of family medicine underscores the discipline's strategic importance in integrated primary health care. Through advocacy, education, research, and partnership with global health institutions, these bodies help articulate a shared vision for family medicine, reinforce its core values, and translate global priorities into locally actionable reforms. The

integration of these organizational strategies with empirical evidence on continuity of care, patient outcomes, health equity, and system resilience reinforces the argument that family medicine is not only central to primary care delivery but also integral to achieving sustainable, equitable, and resilient health systems in the twenty-first century.

The strategic influence of the World Organization of Family Doctors (WONCA) on global family medicine extends beyond advocacy to encompass a deliberate shaping of professional identity, workforce development, and health system transformation. Central to this influence is the organization's focus on defining the competencies and standards expected of family physicians globally. By providing a clear framework for professional practice, WONCA facilitates consistency in clinical quality while allowing adaptability to local contexts. Competency frameworks emphasize not only the clinical dimensions of family medicine but also communication, leadership, research literacy, population health management, and the integration of digital health solutions. This dual focus on standardization and adaptability ensures that family physicians are prepared to deliver high-quality care in diverse settings, ranging from highly resourced urban centers to remote and underserved rural areas. The alignment of professional standards with global primary health care objectives strengthens the credibility of family medicine as a discipline capable of meeting both individual and population-level health needs.

Education and training are key mechanisms through which WONCA operationalizes its vision. By promoting structured postgraduate training programs, accreditation processes, and continuing professional development pathways, the organization fosters a culture of lifelong learning among family physicians. Training curricula supported by WONCA emphasize a holistic approach to patient care, integrating preventive, curative, and rehabilitative services. This holistic focus is essential for addressing the rising burden of chronic non-communicable diseases, which require long-term management strategies that span primary, secondary, and tertiary care. Furthermore, WONCA's emphasis on research training enables family physicians to contribute to the evidence base for primary care interventions, ensuring that clinical practices remain informed by high-quality, contextually relevant data. By supporting the development of research skills, WONCA empowers physicians to critically evaluate emerging innovations, implement quality improvement initiatives, and participate meaningfully in health policy discussions.

A crucial aspect of WONCA's strategy lies in advancing equity in global health. Equity-focused initiatives include policy advocacy, training on culturally competent care, and targeted support for underrepresented groups within the profession. WONCA recognizes that family physicians often serve as the first point of contact for populations facing structural disadvantages, including those affected by socioeconomic deprivation, geographic isolation, or systemic discrimination. By promoting equitable access to care and supporting physicians in navigating social determinants of health, WONCA ensures that family medicine contributes to reducing disparities in health outcomes. The organization also highlights the importance of gender equity within the profession, encouraging policies that enable women family physicians to pursue leadership roles and research opportunities, thereby fostering diversity and inclusivity at all levels of professional activity.

To human resource development, WONCA actively shapes the global primary care landscape through policy engagement. The organization collaborates with international and regional health institutions, including the World Health Organization, to influence policy decisions related to primary care financing, integration of services, and workforce planning. For example, WONCA has contributed to global discussions on universal health coverage, emphasizing the role of family physicians in delivering cost-effective, patient-centered, and coordinated care. Policy influence also extends to the adoption of innovative care delivery models, including team-based approaches, community-oriented primary care, and digital health integration. These interventions are designed to improve continuity of care, enhance patient satisfaction, and optimize health outcomes across populations.

Digital health represents an area of particular strategic importance for the evolution of family medicine. WONCA promotes the integration of telemedicine, electronic health records, and digital decision support tools into primary care practice, recognizing that these technologies can enhance access, efficiency, and quality of care. For instance, teleconsultation platforms can extend the reach of family physicians to rural and underserved communities, while electronic health records facilitate care coordination, longitudinal patient tracking, and data-driven quality improvement initiatives. By actively promoting digital literacy and the ethical use of technology, WONCA ensures that family physicians are equipped to navigate rapidly evolving healthcare environments while maintaining patient-centeredness, confidentiality, and professional standards.

WONCA also fosters global research collaboration through its network of working parties, special interest groups, and practice-based research networks. These structures facilitate the collection and dissemination of primary care data across countries and regions, generating evidence that informs both local practice and international policy. Research themes include chronic disease management, mental health integration, patient safety, health equity, rural health, aging populations, and community-oriented care models. By supporting multicenter and cross-country research initiatives, WONCA enables the identification of best practices, adaptation of interventions to diverse contexts, and dissemination of evidence that strengthens global primary care standards. The resulting body of evidence not only improves clinical outcomes but also informs resource allocation, health workforce planning, and system-level reforms.

The organization's focus on mentorship and leadership development addresses a critical dimension of workforce sustainability. Programs designed to nurture early-career family physicians and future leaders cultivate skills in clinical excellence, research, advocacy, and organizational governance. Mentorship networks facilitate knowledge transfer across generations, strengthen professional identity, and create resilience among practitioners facing the challenges of contemporary healthcare systems. Leadership development is essential not only for individual professional growth but also for systemic impact, as empowered family physicians are better positioned to influence policy, drive innovations in care delivery, and guide quality improvement initiatives.

Equally important is WONCA's engagement with global public health initiatives. Family physicians, as frontline providers, play an essential role in epidemic preparedness, vaccination campaigns, non-communicable disease prevention, and health promotion. WONCA's guidelines, position statements, and collaborative programs help integrate family medicine into national and regional public health strategies, ensuring that primary care remains a cornerstone of resilient health systems. The organization's advocacy for preventive care, early intervention, and community-based services reflects a holistic understanding of health, in which family medicine contributes not only to treatment but also to the prevention of disease and the promotion of overall well-being.

Another strategic focus of WONCA involves the development of regional networks and adaptation of global frameworks to local contexts. While global standards and competencies provide a unifying structure, each region faces unique challenges in terms of health system organization, workforce capacity, cultural expectations, and epidemiological profiles. WONCA supports regional councils and initiatives that allow for tailored strategies, resource sharing, and capacity building, fostering innovation that is contextually relevant. For example, in regions with limited healthcare infrastructure, family physicians may serve as community health leaders, trainers, and coordinators, while in more developed systems, their role may focus on complex care management, chronic disease prevention, and integration of multi-disciplinary teams. These adaptive approaches demonstrate the flexibility of family medicine as a discipline and the importance of organizational support in facilitating its successful implementation across diverse environments.

WONCA's commitment to global health equity also extends to the promotion of research addressing the social determinants of health. Studies supported or endorsed by the organization emphasize the influence of socioeconomic status, education, environment, and access to resources on patient outcomes. By generating evidence on these determinants, family physicians are better equipped to design and implement interventions that address upstream factors affecting health, thereby enhancing the effectiveness of primary care services. The integration of social determinants into clinical practice exemplifies the expanded role of family physicians in bridging clinical care with population health objectives.

The promotion of community engagement is another dimension of WONCA's strategic impact. Family physicians, supported by organizational frameworks and resources, are encouraged to actively participate in community education, health promotion programs, and policy advocacy. This community-centered approach ensures that primary care services are not only clinically effective but also culturally sensitive, responsive to local needs, and socially accountable. Engaging communities in health initiatives strengthens trust, encourages health-seeking behavior, and promotes preventive care, ultimately contributing to improved population health outcomes.

Furthermore, WONCA's initiatives demonstrate the importance of interprofessional collaboration in primary care. Family physicians are increasingly required to coordinate care across a range of healthcare providers, including nurses, pharmacists, allied health professionals, and specialists. WONCA emphasizes the development of skills in team-based care, care coordination, and communication, which are essential for optimizing patient outcomes and ensuring continuity of care. By fostering interprofessional collaboration, family physicians can leverage diverse expertise to address complex health needs, manage chronic conditions, and reduce fragmentation within health systems.

The integration of technology and digital health tools into primary care practice is another focus area that continues to shape the discussion around family medicine. WONCA provides guidance on implementing telemedicine, electronic health records, clinical decision support systems, and mobile health applications. These technologies enhance access, facilitate continuity of care, and improve efficiency. Importantly, WONCA also emphasizes ethical considerations, data privacy, and patient-centered implementation, ensuring that technology serves as a complement to, rather than a replacement for, the therapeutic relationship central to family medicine.

Finally, WONCA's global advocacy underscores the interconnectedness of family medicine with broader health system objectives, including universal health coverage, quality improvement, and resilience in the face of demographic and epidemiologic transitions. By promoting the values of equity, accessibility, and comprehensive care, the organization positions family medicine as a strategic lever for achieving sustainable health system outcomes. The collective efforts of family physicians, supported by global frameworks and organizational initiatives, illustrate the transformative potential of the discipline, extending beyond individual patient care to influence population health, health policy, and societal well-being.

Workforce development is another critical determinant of the future of family medicine. Structured education, competency-based training, interprofessional collaboration, continuous professional development, leadership cultivation, and global health exposure are essential to preparing physicians capable of navigating increasingly complex clinical, social, and technological landscapes. Innovative workforce models, including team-based care, task-sharing, community-based rotations, and integrated digital support, will enhance efficiency, broaden access, and optimize outcomes. Strategic workforce planning, aligned with demographic trends, epidemiological transitions, and system priorities, is essential to ensure that family medicine remains adequately staffed, equitably distributed, and professionally sustained across diverse contexts.

The intersection of family medicine with social determinants of health, equity, and environmental challenges is increasingly recognized as a critical domain of practice, research, and policy. Family physicians are uniquely positioned to identify and address factors such as socioeconomic disparities, educational deficits, housing insecurity, environmental exposures, and behavioral risks, employing interventions that extend beyond clinical care to community engagement, advocacy, and policy influence. Future practice models are anticipated to integrate robust approaches for addressing these determinants, leveraging intersectoral partnerships, evidence-based strategies, and culturally competent care frameworks. This expanded scope reinforces the ethical, societal, and strategic dimensions of the discipline, emphasizing that family medicine contributes not only to clinical outcomes but also to the broader goals of social justice, health equity, and sustainable development.

Emerging challenges, including population aging, multimorbidity, mental health burdens, and global health emergencies, further underscore the strategic relevance of family medicine. Evidence indicates that robust primary care infrastructure anchored in family medicine enhances system resilience, mitigates service disruptions, facilitates early detection and response, and supports population-level preparedness. The discipline's adaptability and community embeddedness position family physicians as critical agents in emergency response, risk communication, and continuity of care during crises such as pandemics, natural disasters, and humanitarian emergencies. Policy frameworks that recognize and support these capacities will be essential to leveraging the full potential of family medicine in enhancing health system preparedness, responsiveness, and sustainability.

Research, knowledge generation, and evidence-informed practice remain central to the evolution of family medicine. The discipline's integration with health systems research, implementation science, population health studies, and translational research ensures continuous learning, refinement of clinical protocols, and informed policy development. Family physicians contribute to generating data on disease patterns, intervention effectiveness, health system performance, and social determinants, facilitating evidence-based improvements at both clinical and systemic levels. The adoption of real-world data, digital health analytics, and participatory research methodologies enables dynamic, contextually relevant insights, strengthening the discipline's contribution to science, policy, and practice while maintaining its patient-centered orientation.

The future sustainability and resilience of health systems are intrinsically linked to the strategic development of family medicine. Health systems should adopt proactive measures to anticipate demographic, epidemiological, and environmental trends, positioning family physicians to respond effectively to the rising prevalence of chronic diseases, multimorbidity, mental health challenges, and climate-related health threats. Emergency preparedness and continuity of care planning must integrate family medicine as a central component, ensuring rapid response, coordination with public health authorities, and maintenance of essential services during crises. Policies and interventions should also support adaptive models of care that can respond to evolving community needs, technological shifts, and global health emergencies, reinforcing the discipline's role in sustaining health system performance under dynamic conditions.

Cultural competence and patient-centeredness remain core elements of practice and policy development. Findings emphasize the need for training, continuous evaluation, and community engagement strategies that enable family physicians to provide care that is respectful, responsive, and tailored to diverse socio-cultural contexts. Health systems should prioritize equitable access for marginalized and vulnerable populations, integrating community health workers, interpreters, and culturally aligned educational resources to enhance engagement, adherence, and satisfaction. Attention to cultural sensitivity and social determinants of health reinforces both ethical practice and health system effectiveness, ensuring that family medicine fulfills its mission to deliver care that is both scientifically sound and socially just.

Future Perspectives

The future of family medicine as a cornerstone of integrated primary health care is poised to undergo profound transformation, influenced by demographic shifts, technological advancements, evolving health system structures, and the increasingly complex health needs of populations worldwide. Projections indicate that the global burden of chronic disease, multimorbidity, and age-related health conditions will continue to rise, necessitating adaptive and anticipatory models of care that extend beyond conventional clinical approaches. Family medicine, with its foundational principles of continuity, comprehensiveness, coordination, and patient-centeredness, is uniquely positioned to address these emerging challenges, offering a flexible and holistic framework capable of integrating clinical, public health, and social dimensions of care in both high- and low-resource contexts. The trajectory of the discipline will be shaped by innovation in practice models, workforce development, health technology, policy alignment, research advancement, and international collaboration, ensuring that family medicine remains a dynamic, responsive, and globally relevant specialty in the twenty-first century and beyond.

One of the foremost areas of evolution in family medicine pertains to the integration of digital health and artificial intelligence into routine practice. Predictive analytics, machine learning algorithms, telemedicine platforms, wearable health devices, and digital decision support systems are increasingly utilized to enhance diagnostic accuracy, monitor patient outcomes, optimize treatment plans, and facilitate preventive care. Future models of family medicine are anticipated to leverage these tools to deliver highly personalized, data-informed care, enabling physicians to anticipate risk, intervene early, and adapt treatment strategies dynamically. However, the adoption of digital technologies will require careful attention to ethical, regulatory, and operational considerations, including patient privacy, data security, algorithmic bias, equity of access, and maintenance of the relational, humanistic aspects of care. The ongoing challenge for policymakers, educators, and practitioners will be to ensure that technological innovation enhances, rather than diminishes, the patient-centered, holistic ethos that defines family medicine.

The expansion of family medicine into preventive, predictive, and population health management functions will continue to define its strategic role in health systems globally. Emerging evidence supports the integration of population health analytics with primary care delivery, enabling family physicians to identify at-risk populations, stratify disease burden, and implement targeted interventions. Predictive modeling of chronic disease trajectories, risk stratification for mental health disorders, and early identification of social determinants of health will enhance the capacity of family medicine to reduce preventable morbidity and mortality. Furthermore, family physicians will increasingly assume leadership roles in population-level health initiatives, coordinating multi-sectoral interventions that address environmental, social, and behavioral determinants. This evolution reflects the discipline's capacity to bridge individual clinical care with systemic public health objectives, reinforcing its relevance in achieving sustainable, equitable, and evidence-informed health outcomes.

Workforce evolution represents another critical dimension shaping the future of family medicine. Anticipated demographic changes, including an aging physician workforce, increasing patient complexity, and evolving professional expectations, necessitate strategic planning for recruitment, retention, and skill development. Training programs are expected to increasingly emphasize interdisciplinary collaboration, leadership, health system literacy, and digital competency, equipping family physicians to navigate complex care environments effectively. Innovations in medical education, such as simulation-based learning, longitudinal community placements, competency-based assessment, and global health rotations, will enhance preparedness for emerging challenges. In addition, task-sharing and team-based care models are likely to become

more prevalent, allowing family physicians to leverage the expertise of nurses, physician assistants, pharmacists, mental health professionals, and social workers. These approaches will enhance efficiency, broaden access, and optimize outcomes, while preserving the relational and continuity aspects central to the discipline.

Global health inequities and disparities will continue to shape the strategic orientation of family medicine. The discipline is uniquely positioned to address inequities through targeted interventions, culturally competent care, and integration with social services. Future models of care are anticipated to incorporate sophisticated frameworks for assessing and mitigating social determinants of health, including economic vulnerability, education, housing, environmental exposures, and access to nutritious food. Policies that facilitate equitable distribution of family physicians, investment in underserved areas, and support for culturally and linguistically appropriate care will be essential to realizing these objectives. The future of family medicine will thus be inextricably linked to broader social and policy efforts aimed at achieving equity, justice, and inclusive health systems.

Climate change and environmental health challenges are emerging as critical determinants of population health, and family medicine will be increasingly tasked with addressing these complex interactions. Evidence suggests that family physicians will play a pivotal role in managing health consequences of environmental exposures, including heat-related illnesses, respiratory conditions, vector-borne diseases, and mental health impacts of climate-related stressors. Future practice models may integrate environmental health screening, community-based interventions, and cross-sectoral collaboration with public health and policy agencies. The discipline's holistic orientation positions it to address these challenges effectively, balancing individual patient care with population-level preventive strategies, while informing policy development on environmental health and sustainability.

Policy evolution and governance will continue to influence the future trajectory of family medicine. Policymakers are expected to prioritize primary care as the backbone of sustainable health systems, aligning financing, workforce development, and service delivery models to support family medicine principles. Innovative payment structures, including value-based care, capitation with performance incentives, and bundled payments, will incentivize comprehensive, preventive, and coordinated care. Governance frameworks that incorporate family physicians into strategic planning, quality assurance, health system design, and emergency preparedness will enhance system responsiveness and resilience. International collaboration, knowledge exchange, and global advocacy will further strengthen the role of family medicine, ensuring that the discipline continues to adapt to emerging health challenges and contributes meaningfully to achieving the Sustainable Development Goals, universal health coverage, and equitable health outcomes worldwide.

Research and knowledge generation will continue to expand the scientific foundation of family medicine, informing evidence-based practice, policy development, and innovation. The future trajectory of the discipline will be characterized by increased engagement in health services research, implementation science, clinical trials, and population health studies. Family physicians are expected to contribute to translational research that bridges clinical practice with community interventions, health systems optimization, and policy implementation. The integration of big data analytics, electronic health records, and real-world evidence will facilitate continuous learning health systems, enabling family physicians to refine practice based on emerging evidence, patient outcomes, and system performance metrics. Moreover, the inclusion of patients as active partners in research, through participatory and co-design methodologies, will enhance relevance, acceptability, and impact of interventions.

Global collaboration and knowledge exchange will play an increasingly prominent role in shaping the future of family medicine. International networks, consortia, and professional organizations

facilitate the dissemination of best practices, educational innovations, policy lessons, and research findings. Comparative studies across diverse health systems enable identification of effective strategies, contextual adaptation, and scaling of successful models. Family medicine's global community will increasingly emphasize collaborative approaches to addressing common challenges, including workforce development, technological integration, health inequities, chronic disease management, and system resilience. These collaborative efforts will reinforce the discipline's capacity to innovate, adapt, and respond to evolving health system demands.

The ethical dimension of family medicine will continue to evolve in response to emerging technological, clinical, and societal challenges. Issues such as genomic medicine, personalized therapeutics, digital health ethics, data privacy, and equitable access will necessitate thoughtful ethical frameworks that balance innovation with patient rights, autonomy, and social justice. Family physicians will be called upon to navigate complex moral landscapes, providing guidance to patients, communities, and health systems while maintaining the relational, patient-centered core of the discipline. Ethical stewardship, cultural competence, and professional integrity will remain foundational to the future practice of family medicine, ensuring that advances in technology, policy, and clinical care serve the broader objectives of health equity and social responsibility.

Integration with other health disciplines and sectors is anticipated to expand in the coming decades, reflecting the interdependent nature of contemporary health challenges. Family medicine will increasingly operate within interdisciplinary teams, collaborating with public health practitioners, mental health specialists, social workers, community organizations, and policymakers to address complex health needs. Cross-sectoral partnerships will enhance the capacity of family physicians to influence social determinants of health, implement preventive interventions, and coordinate care across clinical and community settings. The development of robust interprofessional education, shared clinical protocols, and collaborative practice frameworks will be essential to realizing this vision, ensuring that family medicine functions as both a clinical and systemic integrator within modern health systems.

Demographic changes, including population aging, urbanization, and increasing diversity, will continue to shape the scope and priorities of family medicine. The prevalence of chronic diseases, multimorbidity, and geriatric syndromes will increase the demand for longitudinal, coordinated, and patient-centered care. Family physicians will be required to develop expertise in gerontology, complex care management, palliative care, and integrated mental health support. Policies, training programs, and health system structures will need to accommodate these evolving demands, ensuring that the workforce is adequately prepared and resources are allocated efficiently. Moreover, increasing population diversity will necessitate culturally competent care, language-sensitive communication, and policies that address the unique health needs of migrant, refugee, and marginalized communities.

Innovation in education and professional development will be central to future advances in family medicine. Curricula are expected to incorporate experiential learning, competency-based assessment, interprofessional training, digital literacy, leadership development, research engagement, and community-oriented practice. Lifelong learning frameworks, continuous quality improvement programs, and global educational collaborations will enhance the adaptability, expertise, and professional satisfaction of family physicians. Training programs will increasingly emphasize resilience, emotional intelligence, systems thinking, and advocacy skills, equipping physicians to navigate complex care environments and assume leadership roles within health systems. This evolution will reinforce the strategic capacity of family medicine to respond to emerging challenges, drive innovation, and sustain high-quality primary care globally.

In addition to technological, educational, and policy advancements, family medicine will increasingly focus on addressing systemic inequities, social determinants of health, and health

disparities. Future practice models are anticipated to incorporate comprehensive approaches that address poverty, education, housing, nutrition, environmental exposures, and psychosocial determinants, leveraging intersectoral collaboration and policy advocacy. Family physicians will serve as key agents of social accountability, ensuring that health systems are responsive to the needs of vulnerable populations and that interventions promote equity, inclusion, and justice. Research, policy, and practice will converge to generate evidence-informed strategies that address these determinants at both individual and population levels, further solidifying family medicine's strategic relevance and societal impact.

Global health emergencies, pandemics, and environmental crises will continue to underscore the strategic importance of family medicine. Future perspectives emphasize the capacity of family physicians to maintain continuity of care, provide early detection and response to emerging threats, coordinate with public health authorities, and engage communities in preventive measures. Policies and system design will need to prioritize the resilience, preparedness, and adaptability of family medicine infrastructure, ensuring that primary care remains operational during crises while supporting broader health system objectives. Family medicine's embedded position within communities and health systems positions it as a linchpin for emergency preparedness, risk mitigation, and recovery, highlighting its enduring relevance in the evolving global health landscape.

The synthesis of emerging trends indicates that family medicine will increasingly function as a driver of innovation, system transformation, and knowledge translation. By integrating clinical excellence, public health perspectives, digital technologies, research capacity, workforce development, and policy engagement, family medicine will continue to evolve as a dynamic, adaptive, and strategically essential discipline. The future trajectory of the field will be characterized by a balance between technological innovation and humanistic care, individual clinical responsibility and population-level impact, and professional autonomy and intersectoral collaboration. This multidimensional evolution will ensure that family medicine remains a cornerstone of integrated primary health care, capable of meeting the complex, interconnected health challenges of the twenty-first century and advancing equitable, sustainable, and high-quality health systems globally.

Conclusions

- International collaboration and global discourse have emerged as critical enablers of knowledge exchange, capacity building, and best-practice dissemination. Comparative analyses across diverse health systems inform policy design, educational strategies, technological integration, and workforce deployment. The cultivation of global networks and professional associations enhances the exchange of innovations, supports professional development, and fosters solidarity in addressing shared challenges such as workforce shortages, inequities, technological adoption, and system resilience. Family medicine's global community reinforces the universality of core principles while facilitating adaptation to local contexts, ensuring both standardization of quality and responsiveness to socio-cultural, economic, and epidemiological realities.
- The forward trajectory of family medicine indicates an ongoing expansion of roles encompassing leadership, advocacy, education, research, and health system transformation. Family physicians increasingly assume positions that influence policy, guide intersectoral initiatives, coordinate population health interventions, and contribute to governance structures. These expanded roles reflect the discipline's adaptability, strategic importance, and ethical commitment to advancing comprehensive, equitable, and sustainable health care. By integrating clinical excellence, public health knowledge, policy engagement, and community advocacy, family medicine operates as both a clinical specialty and a system-level enabler, capable of driving transformative change in health outcomes, health equity, and health system performance.

- In summation, the evidence synthesized throughout this article underscores that family medicine is not merely a medical specialty confined to clinical encounters but a multidimensional, adaptive, and strategically essential discipline. Its principles—continuity, comprehensiveness, coordination, patient-centeredness, and community integration—provide a foundation for health system effectiveness, equity, resilience, and sustainability. Technological innovation, workforce development, policy alignment, research engagement, global collaboration, and ethical stewardship collectively define the future trajectory of the discipline, ensuring its relevance and adaptability in the face of emerging global health challenges. Family medicine's integration with primary health care, public health, and social determinants positions it to meet the complex and interrelated needs of populations, reduce disparities, advance evidence-informed practice, and contribute meaningfully to achieving global health objectives, including universal health coverage and the Sustainable Development Goals.
- The strategic and ethical imperative is clear: family medicine must continue to evolve, innovate, and expand while remaining true to its foundational principles. Investment in workforce, education, technology, policy, and research will enable the discipline to realize its full potential, serving as a cornerstone of health systems that are equitable, resilient, patient-centered, and capable of addressing twenty-first-century health challenges. By synthesizing clinical expertise, population health strategies, policy engagement, technological innovation, and global collaboration, family medicine is uniquely positioned to shape the future of integrated primary health care worldwide, ensuring that health systems remain responsive, effective, and just, and that populations achieve optimal health and well-being across the lifespan. The trajectory outlined in this article provides a comprehensive roadmap for the continued advancement, consolidation, and global recognition of family medicine as a vital pillar of twenty-first-century health care, reflecting its enduring relevance, strategic significance, and transformative potential for both patients and societies at large.

Recommendations

- Interprofessional collaboration represents a critical avenue for enhancing the efficiency, quality, and reach of family medicine. Family physicians should be supported in leadership roles within multidisciplinary teams, coordinating care across clinical, social, and community services. Policies and organizational frameworks must facilitate clear communication, shared decision-making, role delineation, and integrated care pathways. The inclusion of allied health professionals, mental health specialists, social workers, and public health practitioners expands the scope of interventions, strengthens continuity, and reduces system fragmentation. Future models should also explore collaborative frameworks that leverage technology, data sharing, and community partnerships to optimize care delivery while preserving relational continuity and patient-centered approaches.
- In the context of global health, family medicine must be integrated into initiatives that address universal health coverage, equity, and sustainable development. Recommendations emphasize alignment of national strategies with international frameworks, such as the Sustainable Development Goals, the World Health Organization's primary health care agenda, and global health security objectives. International partnerships, capacity-building programs, and knowledge exchange networks can enhance the strategic deployment of family medicine, ensuring that lessons from diverse health system contexts inform policy, training, and practice. Global advocacy and professional collaboration will continue to be essential for advancing recognition, resource allocation, and strategic integration of family medicine worldwide.
- The ethical stewardship, professional accountability, and continuous quality improvement must underpin all recommendations for the advancement of family medicine. Health systems should implement robust mechanisms for monitoring outcomes, evaluating performance, maintaining

standards, and promoting transparency. Ethical frameworks should guide the integration of emerging technologies, clinical decision-making, resource allocation, and community engagement. Family physicians should be empowered to act as advocates for patients, communities, and system improvement, reinforcing the discipline's commitment to social responsibility, patient welfare, and evidence-informed practice. Continuous evaluation, reflective practice, and adaptive governance are essential to ensure that family medicine evolves in alignment with societal needs, technological advancements, and health system priorities, maintaining its strategic relevance, ethical integrity, and transformative potential.

- In advancing family medicine requires a coordinated, multi-level approach that addresses workforce development, technological innovation, policy alignment, infrastructure investment, research engagement, interprofessional collaboration, cultural competence, equity, and ethical stewardship. By implementing these recommendations, health systems can ensure that family medicine continues to fulfill its foundational role as a cornerstone of integrated primary health care while evolving to meet the complex, interrelated health challenges of the twenty-first century. Strategic investment, evidence-informed planning, and global collaboration will enable the discipline to expand its scope, enhance its effectiveness, and contribute meaningfully to sustainable, equitable, and high-quality health systems worldwide. These recommendations provide a roadmap for policymakers, educators, clinicians, and researchers to strengthen the impact, resilience, and global relevance of family medicine, ensuring that it remains responsive to the evolving needs of populations and the strategic imperatives of contemporary health care.

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THE KEY ASPECTS OF ADVANCING INTEGRATED PRIMARY HEALTH CARE THROUGH FAMILY MEDICINE: CONCEPTUAL FRAMEWORKS, POLICY IMPLICATIONS, COMPREHENSIVE TRENDS AND LONG-TERM OUTLOOKS IN GENERAL

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Abstract:

Integrated primary health care has increasingly been recognized as a foundational strategy for improving population health outcomes, enhancing equity, and strengthening health system efficiency worldwide. Within this context, family medicine occupies a pivotal and irreplaceable role, functioning as the central clinical and organizational pillar through which integrated, person-centered, and continuous care is delivered. This article provides a comprehensive academic analysis of the key aspects involved in advancing integrated primary health care through family medicine, with particular emphasis on conceptual frameworks, policy implications, global trends, and long-term outlooks. By synthesizing theoretical perspectives, empirical evidence, and comparative international experiences, the study elucidates the multidimensional contributions of family medicine to contemporary health systems and highlights its strategic relevance in addressing complex and evolving health challenges. From a conceptual standpoint, family medicine is grounded in core principles that align intrinsically with integrated primary health care, including continuity, comprehensiveness, coordination, and patient-centeredness. These principles provide a robust theoretical foundation for understanding how family medicine bridges preventive, curative, rehabilitative, and palliative services across the life course. The article examines how these conceptual frameworks have evolved in response to demographic transitions, epidemiological shifts toward chronic and multimorbid conditions, and the growing recognition of social and environmental determinants of health. Family medicine is positioned not merely as a

clinical specialty but as a systemic integrator that connects individuals, families, communities, and health systems, enabling holistic and context-sensitive care delivery. Policy implications constitute a central focus of the analysis, as the effectiveness and sustainability of family medicine are closely linked to governance, financing, and regulatory environments. Evidence consistently demonstrates that health systems prioritizing strong primary care infrastructures anchored in family medicine achieve superior outcomes in terms of access, quality, cost-effectiveness, and equity. The article explores policy mechanisms that support the advancement of integrated primary health care, including workforce planning, education and training frameworks, payment models incentivizing longitudinal and preventive care, and governance structures that embed family physicians in decision-making processes. Conversely, policy fragmentation, underinvestment in primary care, and misaligned incentives are identified as persistent barriers that constrain the full potential of family medicine, particularly in low- and middle-income settings. Global trends further underscore the expanding scope and strategic importance of family medicine. Across diverse regions, family physicians are increasingly engaged in chronic disease management, mental health care, preventive services, community-based interventions, and public health initiatives. The integration of digital health technologies, such as telemedicine, electronic health records, and decision-support systems, has enhanced access, continuity, and care coordination, especially in underserved and remote populations. At the same time, the article critically examines challenges associated with technological integration, including digital inequities, data privacy concerns, and the need to preserve the relational and humanistic dimensions of care that define family medicine. Comparative global experiences illustrate both convergence around core principles and contextual variation in implementation, reflecting differences in resources, culture, and health system organization. The long-term outlook for advancing integrated primary health care through family medicine is shaped by emerging demographic, epidemiological, technological, and environmental pressures. Aging populations, rising multimorbidity, health workforce shortages, and increasing system complexity necessitate adaptive, resilient, and patient-centered care models. Family medicine is uniquely positioned to respond to these demands by fostering continuity, strengthening care coordination, addressing social determinants of health, and enhancing system resilience during public health emergencies and crises. The article emphasizes the importance of sustained investment in education, research, and professional development to ensure that family physicians are equipped with the competencies required for leadership, innovation, and evidence-based practice in evolving health system contexts. The advancing integrated primary health care through family medicine represents both a strategic necessity and an ethical imperative for modern health systems. By aligning conceptual foundations with supportive policy frameworks, responding to global trends, and anticipating long-term challenges, family medicine can continue to serve as a cornerstone of accessible, equitable, and high-quality health care. This analysis provides a comprehensive academic foundation for policymakers, educators, and health professionals seeking to strengthen integrated primary health care and underscores the enduring relevance of family medicine in achieving sustainable health outcomes globally.

Keywords: Family medicine, integrated primary health care, health systems integration, primary care policy, global health trends.

Background

The advancement of integrated primary health care (PHC) represents a central paradigm in modern health system reform, with family medicine established as its essential clinical and organizational engine. This nexus is not incidental but rooted in a compelling evidence base demonstrating that health systems built on strong, person-centered primary care achieve better

health outcomes, greater equity, and higher cost-efficiency. The discourse on advancing integrated PHC through family medicine is therefore multifaceted, encompassing evolving conceptual frameworks, critical policy levers, observable global trends, and projections for long-term sustainability and impact.

Conceptually, the integration of PHC is underpinned by the shift from a fragmented, disease-specific model to a holistic, coordinated system of care. Family medicine provides the ideal conceptual and practical vessel for this integration due to its foundational principles of continuity, comprehensiveness, and first-contact coordination. Theoretical models, such as the World Health Organization's (WHO) operational framework for PHC, position the family physician as the integrator of care—a professional who synthesizes biomedical, psychological, and social perspectives to manage complexity within the context of a trusting longitudinal relationship. This conceptual framework moves beyond mere co-location of services toward true integration, where care is seamlessly coordinated across disciplines (e.g., nursing, mental health, pharmacy) and settings (community, hospital, social care) with the patient's needs and biography at the center. The "paradox of primary care," wherein broader, less specialized care is associated with better outcomes and lower cost, finds its most potent expression in a robust family medicine model.

Policy implications are profound and directly shape the viability of this integration. Governments and payers are pivotal in creating an enabling environment through strategic investment, regulation, and payment reform. Policies that strengthen family medicine include preferential funding for PHC infrastructure, the development of blended payment models that reward value, continuity, and outcomes rather than sheer volume of services, and the formal recognition of family medicine as a specialty with distinct training pathways. Crucially, policies must also address the social determinants of health, empowering family medicine practices to connect patients with community resources, thereby integrating clinical care with public health and social services. Without such supportive macro-level policy, the ideal of integrated PHC remains aspirational, vulnerable to persistent underinvestment and a persistent preference for hospital-centric, specialty-driven care models.

Globally, trends reflect both the diffusion of this model and the challenges of its implementation. In high-income countries, the trend is toward formalizing integrated care networks, often led by family physicians within accountable care organizations or health maintenance systems, heavily leveraging digital health tools for coordination. In low- and middle-income countries, the drive towards Universal Health Coverage (UHC) has renewed focus on family medicine as a strategy to expand access to essential services and rationalize limited resources, though often hampered by workforce shortages and inadequate training capacity. A universal trend is the expansion of the family physician's role to include population health management, leadership of multidisciplinary teams, and the use of data for quality improvement. However, countervailing trends, such as physician burnout, professional brain drain, and the commercial fragmentation of care, pose significant threats to integration efforts worldwide.

The long-term outlook for integrated PHC through family medicine is cautiously optimistic but contingent on systemic commitment. The future trajectory points toward a more data-informed, technology-enhanced, and community-embedded practice. Digital tools, from telehealth to artificial intelligence for clinical decision support, promise to extend the reach and precision of family medicine, freeing physicians to focus on complex care and human interaction. The ultimate long-term goal is a sustainable system where family medicine functions as the continuous core, coordinating a spectrum of services to maintain health, manage illness, and navigate complexity across the life course. Achieving this requires sustained advocacy, educational innovation to prepare future generations of family physicians for these expanded roles, and relentless focus on measuring what matters: the health and well-being of populations. The success of this endeavour will be a definitive determinant of global health equity and resilience in the 21st century.

The historical and contemporary background of family medicine provides critical insight into the evolution of the discipline as a cornerstone of integrated primary health care. Historically, family medicine emerged from the recognition that health care systems dominated by specialty-focused, hospital-centered approaches were insufficient to address the broad spectrum of population health needs. Early conceptualizations of primary care emphasized the importance of accessible, continuous, and comprehensive services that could bridge preventive, curative, and rehabilitative care, particularly in communities with limited access to specialized health services. Over the decades, family medicine evolved as a formalized specialty in response to these needs, incorporating both the principles of holistic patient care and the operational frameworks required for effective integration within national health systems. The development of family medicine was influenced by multiple social, economic, and epidemiological factors, including urbanization, industrialization, population growth, and the emergence of chronic and lifestyle-related diseases. These contextual dynamics necessitated a reevaluation of medical education, health workforce planning, and care delivery models, ultimately establishing family medicine as an essential component of sustainable, equitable, and effective health systems.

The institutionalization of family medicine as a distinct specialty occurred across diverse global contexts, shaped by cultural, political, and health system-specific factors. In high-income countries, the establishment of formal family medicine training programs in the mid-twentieth century responded to the growing need for physicians capable of providing continuous care across the lifespan, coordinating specialist interventions, and addressing the psychosocial determinants of health. National medical associations and academic institutions formalized curricula emphasizing clinical breadth, preventive care, and patient-centered communication, creating a professional identity distinct from traditional general practice. In low- and middle-income countries, family medicine emerged as both a strategy to enhance primary care capacity and a mechanism to address inequities in access, quality, and continuity of care. Here, the discipline was often introduced through health system reform initiatives, international collaborations, and public health programs designed to integrate clinical services with community-based interventions. The global evolution of family medicine reflects a convergence of professional, systemic, and policy imperatives, highlighting the discipline's adaptability and strategic significance in diverse healthcare environments.

Epidemiological transitions have profoundly influenced the conceptualization and practice of family medicine. The shift from communicable to non-communicable diseases, coupled with increasing life expectancy and demographic aging, has intensified the demand for longitudinal, patient-centered care. Family physicians are uniquely positioned to manage the complex interplay of multimorbidity, chronic disease progression, and psychosocial factors, ensuring continuity and coordination across multiple levels of care. This expanded scope necessitates competencies in preventive medicine, chronic disease management, health promotion, and interprofessional collaboration, situating family medicine at the nexus of clinical practice and public health. Furthermore, the integration of family medicine into health systems supports early detection and intervention, reduces hospital admissions, and optimizes resource utilization, thereby enhancing system efficiency and resilience.

Global health frameworks have consistently recognized the strategic importance of family medicine in achieving universal health coverage and sustainable health outcomes. The Alma-Ata Declaration of 1978 established primary health care as a fundamental human right and identified comprehensive, community-oriented services as central to achieving health equity. Family medicine, by providing continuous, comprehensive, and coordinated care, operationalizes the principles articulated in this foundational declaration. Subsequent international initiatives, including the Millennium Development Goals and the Sustainable Development Goals, have reinforced the relevance of primary care, emphasizing the role of family physicians in addressing

social determinants of health, reducing disparities, and promoting preventive and population health interventions. The integration of family medicine within these global frameworks underscores the discipline's dual responsibility: to deliver high-quality individual care and to contribute to system-level objectives that enhance population health, equity, and resilience.

The contemporary practice of family medicine reflects the integration of traditional clinical skills with emerging innovations in health care delivery, technology, and population health. Advances in digital health, telemedicine, electronic health records, and predictive analytics have transformed the capacity of family physicians to monitor, prevent, and manage disease. Telehealth platforms, in particular, have facilitated access to care in underserved regions, enabling real-time consultations, remote monitoring, and continuity of care despite geographic or logistical barriers. Digital health systems also support population health management, providing data for surveillance, trend analysis, and targeted interventions. These technological innovations, while enhancing efficiency and reach, necessitate new competencies for family physicians, including digital literacy, data interpretation, and ethical management of sensitive health information. The incorporation of technology must be balanced with the relational and patient-centered aspects that define the discipline, ensuring that care remains holistic, continuous, and responsive to individual needs.

Socioeconomic determinants of health constitute another critical dimension shaping the background of family medicine. Social, economic, and environmental factors exert significant influence over health outcomes, contributing to disparities in access, quality, and equity of care. Family physicians are uniquely positioned to address these determinants through community engagement, patient advocacy, and integration of social support services into care plans. By understanding the complex interrelations between individual behaviors, social contexts, and health system structures, family medicine contributes to a comprehensive model of care that bridges clinical medicine with public health and social policy. This approach enhances both individual and population health outcomes, emphasizing preventive strategies, early intervention, and the mitigation of health inequities.

Educational and workforce considerations also underpin the background of family medicine. Effective practice requires rigorous training that integrates clinical skills with competencies in health systems management, communication, leadership, and public health. The establishment of standardized curricula, accreditation systems, and continuing professional development frameworks has been pivotal in professionalizing the discipline, ensuring consistent quality of care, and fostering a global community of family physicians capable of responding to diverse health system challenges. In addition to initial training, ongoing professional development supports the adaptation of family medicine to emerging epidemiological trends, technological innovations, and evolving patient expectations. Educational reforms that emphasize experiential learning, community-based practice, and interprofessional collaboration strengthen the capacity of family physicians to deliver high-quality, integrated care, and to contribute meaningfully to system-wide improvements in health outcomes.

Policy frameworks and governance structures have exerted profound influence on the evolution and institutionalization of family medicine. National health policies that prioritize primary care, allocate resources strategically, and recognize the centrality of family physicians in health system design have been associated with improved population health indicators, reduced inequities, and enhanced system efficiency. Conversely, inadequate policy support, fragmented health financing, and misaligned incentive structures can undermine the development of family medicine, limiting access, continuity, and comprehensiveness of care. The alignment of policy, governance, and professional standards is therefore essential to realizing the potential of family medicine as a cornerstone of integrated primary health care. International collaboration, comparative health

systems research, and advocacy by professional associations have played pivotal roles in shaping policy environments conducive to the expansion and recognition of family medicine globally.

Cultural and social contexts further shape the background and practice of family medicine. Health beliefs, traditions, and norms influence patient expectations, care-seeking behaviors, and adherence to medical interventions. Family physicians operate at the intersection of these cultural dimensions, requiring sensitivity to local contexts while adhering to evidence-based practice. Cultural competence is therefore both a theoretical and practical imperative, ensuring that interventions are not only clinically appropriate but also socially acceptable and sustainable. By integrating cultural understanding with clinical expertise, family medicine strengthens patient engagement, trust, and therapeutic alliance, enhancing the effectiveness and relevance of care across diverse populations.

The challenges faced by family medicine in contemporary health systems are multifaceted. Workforce shortages, inequitable distribution of practitioners, limited infrastructure, and insufficient remuneration undermine the capacity of the discipline to meet population needs. Additionally, the increasing complexity of patient care, driven by multimorbidity, aging populations, and technological advancement, demands continuous adaptation, innovation, and interprofessional collaboration. Policy, educational, and institutional support is critical to overcoming these barriers, enabling family physicians to fulfill their expanded roles in preventive care, chronic disease management, community engagement, and health system leadership. Addressing these challenges is particularly salient in low- and middle-income countries, where resource constraints, fragmented service delivery, and sociocultural barriers present significant obstacles to effective primary care delivery.

Finally, the background of family medicine is intimately linked with research, knowledge generation, and evidence-based practice. The discipline contributes to health systems research, health policy analysis, clinical trials, and population health studies, generating knowledge that informs practice, guides policy, and strengthens health system resilience. The integration of research into family medicine ensures that interventions are scientifically grounded, contextually relevant, and responsive to emerging health challenges. By fostering a culture of inquiry, reflective practice, and continuous learning, family medicine not only advances clinical and public health knowledge but also reinforces its legitimacy, recognition, and strategic importance within national and global health systems.

The background of family medicine reflects its historical evolution, theoretical foundations, and contemporary adaptation to the complex demands of integrated primary health care. The discipline has emerged in response to demographic, epidemiological, social, and technological transformations, establishing itself as a central pillar of accessible, equitable, and comprehensive health systems. Family medicine integrates clinical expertise, preventive strategies, population health approaches, and social determinants of health into a cohesive model of care, balancing individual patient needs with systemic objectives. Educational frameworks, policy support, technological innovations, and cultural competence collectively enable the discipline to fulfill its expanded roles, addressing chronic disease, mental health, and health inequities while promoting system resilience and sustainability. Understanding this background is essential for appreciating the current scope, challenges, and strategic directions of family medicine globally, and for guiding future research, policy, and practice that reinforce its centrality in twenty-first-century integrated primary health care.

Theoretical and conceptual framework:

The theoretical and conceptual foundations of family medicine are deeply intertwined with the broader principles of primary health care, health systems strengthening, and population health. At its core, family medicine is predicated on the integration of clinical expertise with a holistic

understanding of the patient in the context of their familial, social, and environmental milieu. The discipline is distinguished by its commitment to continuity of care, comprehensiveness, coordination, and patient-centeredness, which together constitute the essential pillars upon which the specialty is built. These pillars provide both a conceptual lens for understanding the function of family medicine within health systems and a theoretical basis for evaluating its contributions to health outcomes, equity, and system resilience in the twenty-first century. By situating family medicine within this conceptual framework, scholars and policymakers can elucidate the mechanisms through which it influences individual, community, and population health, while also identifying the structural, professional, and policy factors that facilitate or constrain its efficacy.

Continuity of care represents a central theoretical construct in family medicine, reflecting the enduring relationship between the physician and the patient over time and across diverse health encounters. This continuity is not merely temporal but also relational, encompassing the development of trust, mutual understanding, and a shared commitment to health goals. The theoretical importance of continuity lies in its capacity to enhance diagnostic accuracy, improve adherence to therapeutic regimens, and facilitate early identification of emerging health issues. Longitudinal engagement enables family physicians to perceive patterns in patient health trajectories, to anticipate risk factors, and to intervene proactively in ways that reduce the burden of chronic disease, prevent complications, and optimize functional outcomes. Conceptually, continuity also supports the integration of preventive, curative, and rehabilitative services, enabling a seamless transition between different levels of care and between various components of the health system. This principle reinforces the notion that family medicine is uniquely positioned to provide comprehensive, coordinated care that is responsive to both individual and population health needs.

Comprehensiveness constitutes another critical element of the theoretical framework, emphasizing the breadth of services and responsibilities encompassed by family medicine. Unlike specialty care, which often focuses on discrete organ systems or narrow clinical domains, family medicine addresses the full spectrum of health concerns, encompassing acute and chronic conditions, preventive interventions, mental health, social and environmental determinants of health, and end-of-life care. This comprehensiveness is conceptually grounded in the recognition that health is multidimensional, and that effective care requires attention to the interplay of biological, psychological, and social factors. By embracing a broad scope of practice, family physicians are able to respond to the complex and evolving needs of individuals and communities, providing interventions that are contextually appropriate, culturally sensitive, and grounded in evidence-based medicine. Furthermore, the integration of comprehensive care within primary health care systems enhances system efficiency, reduces duplication of services, and mitigates fragmentation, thereby reinforcing the role of family medicine as a linchpin in achieving equitable and sustainable health outcomes.

Coordination of care represents a complementary theoretical dimension, reflecting the role of family physicians as orchestrators of multidisciplinary interventions across the health system. Effective coordination ensures that patients receive timely, appropriate, and complementary services from various providers, while minimizing gaps, redundancies, and inefficiencies. Conceptually, coordination encompasses the management of referrals to specialists, integration of diagnostic and therapeutic information, communication across professional teams, and alignment of care with patient preferences and social circumstances. In complex cases involving multimorbidity or psychosocial challenges, the capacity of family physicians to synthesize information from multiple sources and to implement cohesive care plans is critical to achieving favorable outcomes. This theoretical principle also underscores the systemic value of family medicine, demonstrating how a well-integrated primary care specialty contributes to health

system resilience, optimizes resource utilization, and supports continuity across levels of care. The coordination function, therefore, is not merely operational but represents a conceptual bridge linking individual patient encounters with broader health system objectives.

Patient-centeredness forms an additional theoretical cornerstone, reflecting the ethical and professional commitment of family medicine to respect and respond to patient values, preferences, and needs. Patient-centered care is grounded in the recognition that health outcomes are influenced not only by clinical interventions but also by social, cultural, and behavioral determinants. Within this framework, family physicians are encouraged to engage patients as active partners in decision-making, to facilitate shared understanding of health conditions, and to support self-management strategies that promote autonomy and well-being. Conceptually, patient-centeredness intersects with continuity, comprehensiveness, and coordination, creating a cohesive model in which care is tailored to the individual while remaining integrated within the broader health system. The theoretical emphasis on patient-centeredness also aligns family medicine with contemporary health paradigms that prioritize empowerment, engagement, and equity, reinforcing the specialty's role in promoting both clinical excellence and social responsibility.

The conceptual framework of family medicine is further informed by health systems theory, which situates the specialty within the broader organizational, economic, and policy contexts that shape care delivery. Health systems theory emphasizes the interdependence of resources, service delivery, governance, financing, and workforce, highlighting the mechanisms through which primary care interventions influence population-level outcomes. Within this theoretical paradigm, family medicine serves as a structural and functional node, connecting patients, communities, and higher levels of care, while facilitating information flow, resource allocation, and quality improvement initiatives. The integration of family medicine within health systems theory enables the analysis of both micro-level clinical interactions and macro-level policy effects, providing a comprehensive lens for evaluating the impact of family physicians on accessibility, efficiency, equity, and responsiveness of health services. This approach also underscores the need for supportive policy frameworks, investment in infrastructure, and recognition of professional autonomy to ensure that family medicine can fully realize its theoretical potential as a cornerstone of integrated primary health care.

The application of socioecological theory further enriches the conceptual understanding of family medicine, emphasizing the dynamic interactions between individual health behaviors and the broader social, environmental, and cultural determinants of health. Socioecological models posit that health outcomes are influenced by multiple levels of interaction, including individual, interpersonal, organizational, community, and policy contexts. Family medicine, by its very nature, operates at these multiple levels, integrating clinical care with public health initiatives, community engagement, and advocacy for structural reforms. This theoretical perspective underscores the role of family physicians not only as clinical practitioners but also as facilitators of social change, capable of addressing upstream determinants of health, promoting preventive strategies, and engaging with stakeholders to optimize community well-being. By adopting a socioecological lens, the discipline is positioned to navigate the complexities of health inequities, population diversity, and systemic challenges, reinforcing its centrality within integrated primary health care.

The concept of resilience, both at the individual and health system levels, constitutes an emergent theoretical dimension relevant to family medicine in the twenty-first century. Resilience theory emphasizes the capacity of individuals, organizations, and systems to anticipate, adapt, and recover from adverse events, disruptions, or stressors. Within family medicine, resilience manifests in the ability of physicians to manage complex caseloads, respond to emergent health threats, and maintain continuity of care amidst resource constraints or systemic pressures. At the health system level, the integration of family medicine enhances resilience by providing stable,

accessible, and comprehensive primary care services that buffer against shocks, mitigate the impact of epidemics or disasters, and maintain functional continuity across levels of care. The theoretical emphasis on resilience complements the principles of continuity, coordination, and comprehensiveness, illustrating how family medicine contributes not only to immediate patient outcomes but also to the long-term adaptability and robustness of health systems.

Evidence-based practice constitutes another essential theoretical and conceptual pillar, grounding family medicine in the systematic application of research evidence to clinical decision-making. The integration of scientific knowledge with clinical expertise and patient preferences ensures that interventions are both effective and contextually appropriate. The theoretical framework of evidence-based family medicine encompasses the generation, dissemination, and implementation of research findings, as well as the continuous evaluation of practice outcomes. By adopting a rigorous evidence-based orientation, family medicine reinforces its credibility, supports informed health policy decisions, and contributes to the standardization and quality improvement of primary care services globally. This orientation also fosters a culture of continuous learning, critical appraisal, and reflective practice among family physicians, aligning the discipline with contemporary expectations for accountability, transparency, and professional excellence.

Finally, the conceptual framework of family medicine encompasses ethical and social dimensions, emphasizing the moral obligations of physicians to promote justice, equity, and beneficence. Ethical theory informs the practice of family medicine by guiding decisions that balance individual patient needs with societal priorities, resource constraints, and public health considerations. The social contract between physicians and communities establishes expectations regarding accessibility, quality, and responsiveness, reinforcing the role of family medicine as both a clinical and civic institution. By integrating ethical, social, and theoretical considerations, the discipline provides a comprehensive model for understanding health care delivery that transcends biomedical paradigms and encompasses the full spectrum of human experience, social context, and systemic interdependencies.

The theoretical and conceptual framework of family medicine is multidimensional, encompassing principles of continuity, comprehensiveness, coordination, patient-centeredness, health systems integration, socioecological awareness, resilience, evidence-based practice, and ethical responsibility. These interconnected constructs provide both a lens for understanding the evolving scope and function of the discipline and a foundation for evaluating its impact on individual, community, and population health outcomes. Situated at the intersection of clinical practice, public health, and health systems theory, family medicine emerges as a dynamic, adaptive, and strategically significant specialty capable of responding to the complex health challenges of the twenty-first century. By grounding practice in these theoretical and conceptual underpinnings, the discipline not only ensures the delivery of high-quality, equitable, and patient-centered care but also reinforces its central role as the cornerstone of integrated primary health care globally. These frameworks provide the necessary analytical foundation for subsequent examinations of the scope, challenges, expanded roles, and future directions of family medicine in diverse health system contexts, highlighting both its enduring relevance and its capacity for continued evolution in response to emerging global health imperatives.

Results and Discussion

The synthesis of the global literature and policy documents reveals a complex but coherent picture of the role of family medicine in advancing integrated Primary Health Care (PHC). The results are not merely a collection of discrete findings but an interconnected narrative that demonstrates both the proven efficacy of the model and the significant hurdles to its full realization. This section integrates results and discussion across key thematic areas: the evidence for impact, the mechanisms of integration, persistent systemic challenges, innovative adaptations, and the evolving identity of the discipline.

The Evidence Base: Correlates and Outcomes of Strong Family Medicine

A robust body of evidence forms the foundational result underpinning all policy discourse: health systems with a strong foundation of family medicine consistently demonstrate superior performance. Research across diverse settings shows a clear correlation between the density of family physicians and improved population health outcomes, including lower mortality rates, particularly from amenable causes. The result is not only improved clinical metrics but also systemic efficiencies. Studies indicate that systems oriented towards family medicine and integrated PHC achieve higher levels of equity in access to services, greater patient satisfaction, and lower overall healthcare costs due to reduced unnecessary hospitalizations and more appropriate specialist utilization. For instance, the core dimensions of primary care—first contact, longitudinality, comprehensiveness, and coordination—as operationalized by family medicine, have been systematically linked to better health, more equitable distribution of health, and greater efficiency. These results provide an incontrovertible argument for the model, translating the conceptual framework of person-centered, continuous care into tangible benefits for individuals and health economies. The discussion therefore moves from questioning *if* family medicine is a cornerstone to investigating *how* its integration can be optimally implemented and sustained.

Mechanisms of Integration: From Theory to Operational Models

The results of implementation science highlight several key mechanisms through which family medicine advances integration. The first is the relational continuity provided by a personal family physician. This ongoing relationship is itself a tool for integration, as the physician accumulates knowledge of the patient's history, preferences, and social context, enabling them to act as a skilled navigator and interpreter of the wider health system. This personal continuity facilitates informational and management continuity across different providers and settings.

The mechanism is the structural and professional role of the family physician as a coordinator. In successful integrated models, the family physician is formally recognized as the central node in the care network. This is operationalized through shared electronic health records, explicit referral and discharge protocols, and the family physician's leadership within multidisciplinary teams (MDTs). The discussion here revolves around the shift from a passive "gatekeeper" role to an active "navigator and integrator" role. Results from various integrated care pilots show that when family physicians are given the tools, time, and mandate to coordinate care—especially for complex patients with multimorbidity—the outcomes include reduced duplication of tests, fewer medication errors, and a more coherent care experience for the patient.

Another critical mechanism is community-oriented primary care (COPC), an expanded model where family medicine practices use epidemiological methods to understand the health needs of their registered population and engage in community partnerships to address them. This represents a powerful form of integration, bridging clinical medicine with public health. Results from practices employing COPC approaches demonstrate effectiveness in targeted prevention campaigns and managing chronic diseases at a population level within their practice. The discussion highlights this as a vital expansion of the family medicine role, moving beyond the consulting room to influence the health of a defined community.

Persistent Systemic Challenges and Implementation Gaps

Despite the strong evidence and identifiable mechanisms, the results of global health system analysis reveal persistent challenges that stifle integration. A primary result is the nearly universal issue of misaligned financial incentives. Fee-for-service models that reward volume and procedures over cognitive care, coordination, and prevention directly undermine the principles of integrated PHC. The discussion centers on the need for payment reform towards blended capitation or global budget models that financially support continuity, team-based care, and quality outcomes, allowing family physicians the necessary time for complex care coordination.

Another stark result is the workforce crisis. There is a critical shortage of family physicians in both rural and underserved urban areas worldwide, exacerbated by international migration and the lower professional status often ascribed to generalism compared to specialties. This shortage is a fundamental barrier to integration, as an overburdened, demoralized workforce cannot fulfill the expansive role envisioned. The discussion extends to medical education systems that frequently devalue primary care careers and fail to provide adequate training in leadership, system science, and population health—skills essential for the integrating physician of the 21ST century.

Furthermore, results indicate that information system fragmentation remains a major technical obstacle. The lack of interoperable electronic health records that seamlessly connect primary care, hospitals, pharmacies, and social services forces integration to rely on slow, unreliable methods like fax and phone, compromising safety and efficiency. The discussion emphasizes that digital infrastructure is not a luxury but a core requirement for modern integrated care, and its absence represents a critical policy failure.

Innovative Adaptations and Evolving Roles

In response to these challenges, the results showcase a wave of innovation adapting family medicine for 21st-century needs. A significant trend is the rapid integration of digital health tools, accelerated by the COVID-19 pandemic. Results from telehealth implementation demonstrate its efficacy in maintaining continuity for chronic disease management, mental health, and follow-up care, thereby enhancing access and integration for geographically or mobility-constrained patients. However, the discussion cautions against a purely virtual model, emphasizing the need for a “hybrid” approach that blends digital convenience with essential in-person, relational care to avoid exacerbating inequities for those lacking digital literacy or access.

Another key result is the formalization of advanced team-based structures. The family physician is increasingly the clinical leader of an MDT including nurse practitioners, clinical pharmacists, social workers, and community health workers. Research results show that such teams can expand capacity, improve adherence to clinical guidelines, and more effectively address social determinants of health. The discussion revolves around the need for clear scopes of practice, effective communication channels, and a culture of shared responsibility to make these teams function optimally, moving from a hierarchy to a true partnership.

The scope of practice itself is also evolving, with results showing family physicians in various contexts taking on expanded responsibilities in areas like point-of-care ultrasound, minor surgery, hospitalist care, and palliative care. This “vertical integration” within the family physician’s own skill set can enhance continuity and reduce system fragmentation, particularly in rural or resource-limited settings where referral is not a simple option. The discussion balances this with warnings against role overload and the necessity of maintaining the generalist’s core competency in breadth over excessive depth in a few areas.

The Evolving Identity and Future Trajectory

The cumulative results point to an ongoing evolution in the professional identity of family medicine. It is maturing from a discipline defined by what it is not (not a specialty) to one confidently defined by its unique expertise: managing complexity, uncertainty and multimorbidity within enduring human relationships. The discussion posits that the future of integrated PHC depends on this confident identity being recognized by policymakers, health system leaders, and the public.

The long-term outlook suggests several interconnected directions. Family medicine must become more politically and strategically assertive, actively engaging in health system governance to advocate for the necessary policy and financing reforms. The educational curricula must be transformed to equip future family physicians with competencies in data analytics, quality improvement, change management, and advocacy alongside clinical excellence. Third, research

must continue to build the business case, generating localized evidence on the cost-effectiveness of integrated, family medicine-led models to persuade national and regional payers.

The results affirm that family medicine is not merely a component but the essential catalytic agent for achieving integrated PHC. Its core features are precisely those required to navigate the complexity of modern health needs. The discussion, however, reveals that its potential is constrained by systemic, financial, and cultural headwinds. The path forward requires a dual focus: strengthening the internal capabilities and identity of the discipline while relentlessly advocating for the external system reforms that will allow it to flourish. The ultimate result of this endeavor will determine whether the vision of equitable, efficient, and person-centered health systems can move from a well-evidenced concept to a universal reality.

The results of the comprehensive review and conceptual analysis of family medicine as a cornerstone of integrated primary health care reveal a complex and multidimensional discipline whose impact extends across clinical, community, systemic, and global domains. The findings indicate that family medicine has evolved into a specialty characterized by continuity, comprehensiveness, coordination, and patient-centeredness, with its scope significantly expanding in response to demographic transitions, epidemiological shifts, technological innovation, and evolving health system expectations. Analysis of the literature demonstrates that family medicine plays a critical role in enhancing access, quality, and equity in health care, particularly in settings with fragmented service delivery or limited specialist availability. Across diverse global contexts, the integration of family physicians into primary care systems has been associated with improved health outcomes, reduced hospitalizations, enhanced preventive care uptake, and more efficient utilization of resources, reinforcing its strategic relevance as a central pillar of health systems.

Empirical evidence indicates that continuity of care is a defining strength of family medicine, producing measurable improvements in both patient and system-level outcomes. Longitudinal relationships between patients and family physicians facilitate early detection of disease, timely intervention, and adherence to preventive and therapeutic regimens. Patients report higher satisfaction, trust, and engagement when they experience consistent care over time, which in turn correlates with improved health behaviors and reduced morbidity. Continuity also enables physicians to contextualize health concerns within the patient's life course, recognizing patterns of risk, familial predispositions, and social determinants that may otherwise go unaddressed in episodic care models. These findings underscore the theoretical assertion that relational continuity is both an operational and ethical cornerstone of family medicine, supporting the delivery of personalized, evidence-informed, and socially responsive care.

Comprehensiveness emerges as another critical dimension in the results, reflecting the capacity of family medicine to address a broad spectrum of health needs across the lifespan. The literature indicates that family physicians manage both acute and chronic conditions, integrate mental health care, provide preventive services, and coordinate rehabilitative interventions. In high-income countries, family physicians often lead chronic disease management programs, including diabetes, hypertension, cardiovascular disease, and multimorbidity, demonstrating measurable reductions in complications and hospital admissions. In low- and middle-income countries, family physicians frequently function as primary providers for a wide range of conditions, including infectious diseases, maternal and child health concerns, and neglected tropical diseases, while also engaging in community health promotion and preventive initiatives. The breadth of practice underscores the adaptability of family medicine, its alignment with integrated primary health care principles, and its capacity to respond to both individual patient needs and broader population health imperatives.

Coordination of care constitutes a pivotal mechanism through which family medicine influences health system performance. Evidence indicates that family physicians enhance the efficiency,

safety, and effectiveness of care by facilitating communication between specialists, allied health professionals, and community-based services. Care coordination mitigates the risks associated with fragmented health systems, such as duplicated investigations, inconsistent treatment plans, and gaps in follow-up, particularly for patients with complex or chronic conditions. Comparative analyses across health systems demonstrate that countries with robust family medicine integration report lower rates of avoidable hospitalizations, reduced health care costs, and improved continuity of preventive services. These findings reinforce the theoretical proposition that coordination is a central operational function of family medicine, linking clinical encounters to system-level objectives and ensuring that individual care contributes to broader health system resilience and efficiency.

Patient-centeredness is consistently highlighted in the results as a defining feature of family medicine that enhances clinical outcomes, patient satisfaction, and engagement. The literature demonstrates that patient-centered approaches, which prioritize individual preferences, values, and social contexts, improve adherence to treatment, facilitate shared decision-making, and enhance overall well-being. Family physicians' capacity to integrate patient-centered care with evidence-based interventions is particularly valuable in addressing complex and chronic conditions, where lifestyle modification, self-management, and behavioral change are critical to outcomes. Furthermore, the incorporation of culturally competent care practices allows family physicians to navigate diverse patient populations, respecting social norms and mitigating barriers to access and adherence. These findings substantiate the theoretical and conceptual frameworks emphasizing the ethical and relational dimensions of family medicine, illustrating that the discipline is both scientifically rigorous and socially responsive.

The analysis of health system integration reveals that family medicine contributes significantly to system-wide efficiency, equity, and resilience. Countries with well-established family medicine frameworks demonstrate higher primary care utilization, lower secondary and tertiary care expenditure, and improved population health indicators, including reduced mortality, improved vaccination coverage, and better chronic disease control. Health systems with strong family medicine integration also exhibit enhanced capacity for emergency preparedness and response, leveraging the accessibility and relational continuity of primary care to maintain service delivery during crises, such as pandemics or natural disasters. These findings corroborate resilience theory perspectives, highlighting the role of family medicine in buffering health systems against shocks and ensuring continuity, adaptability, and sustained quality of care.

Technological integration emerges as both an opportunity and a challenge in the contemporary practice of family medicine. The literature indicates that the adoption of electronic health records, telemedicine, digital health platforms, and predictive analytics improves monitoring, care coordination, and access, particularly in underserved or rural regions. Telehealth has demonstrated efficacy in managing chronic disease, providing mental health support, and enhancing preventive care engagement. However, studies also highlight challenges associated with technological adoption, including the need for digital literacy, potential depersonalization of care, inequities in access to technology, and ethical considerations regarding data privacy and security. These findings suggest that while technology can augment the effectiveness of family medicine, careful integration is necessary to preserve the relational, patient-centered, and holistic aspects that define the discipline.

Workforce development and education emerge as central determinants of family medicine's effectiveness and sustainability. The results indicate that countries with structured training programs, continuing professional development, and standardized accreditation demonstrate higher physician competence, improved patient outcomes, and greater system integration. Training curricula that emphasize experiential learning, community-based rotations, interprofessional collaboration, and health systems literacy equip family physicians to navigate

complex clinical, social, and systemic challenges. Furthermore, educational frameworks that foster research engagement and critical appraisal skills strengthen evidence-based practice, ensuring that family physicians contribute to the generation, dissemination, and application of knowledge. Conversely, insufficient training, inadequate workforce distribution, and limited professional recognition constrain the discipline's capacity to fulfill its expanded roles, particularly in resource-limited or rural settings.

The results also underscore the significance of policy, governance, and financing structures in shaping the effectiveness and reach of family medicine. Supportive policies that prioritize primary care, allocate resources strategically, and recognize family physicians' centrality in health systems are associated with improved access, continuity, and equity. Payment models that reward longitudinal care, preventive interventions, and care coordination incentivize practice behaviors aligned with the principles of family medicine. Conversely, fragmented financing, undervaluation of primary care services, and policy neglect impede the discipline's capacity to achieve its full potential. Comparative analyses reveal that policy alignment, coupled with workforce development and educational support, is critical to the global dissemination of effective family medicine practices.

Integration with public health initiatives represents a further dimension of family medicine's expanded role. The literature demonstrates that family physicians contribute to health promotion, disease prevention, surveillance, and community engagement, bridging the gap between clinical medicine and population health. Examples include vaccination campaigns, screening programs, health literacy initiatives, and interventions addressing social determinants of health. These contributions enhance preventive care uptake, reduce disease burden, and foster health equity, highlighting the multifaceted impact of family medicine beyond individual clinical encounters. The evidence indicates that the integration of clinical and public health responsibilities strengthens health system responsiveness, enhances community trust, and positions family medicine as a strategic instrument in achieving universal health coverage.

Challenges identified in the literature include workforce shortages, uneven geographic distribution of physicians, resource limitations, and increasing patient complexity. Rural and underserved areas often experience gaps in access, limiting the capacity of family medicine to provide comprehensive, continuous care. Additionally, the increasing prevalence of multimorbidity, aging populations, and social complexity intensifies the cognitive and organizational demands on family physicians. Addressing these challenges requires strategic workforce planning, supportive policy frameworks, interprofessional collaboration, and the integration of innovative care delivery models. The results indicate that health systems that prioritize these strategies demonstrate improved outcomes, enhanced efficiency, and increased physician satisfaction, underscoring the interdependence of structural, professional, and systemic factors in optimizing family medicine's contribution.

The discussion of results highlights the theoretical and practical implications of the findings, emphasizing the alignment between conceptual principles and empirical evidence. Continuity, comprehensiveness, coordination, patient-centeredness, and system integration emerge consistently as both theoretical constructs and observable outcomes in practice. The synthesis illustrates that family medicine functions not only as a clinical specialty but as a strategic agent within health systems, capable of advancing equity, quality, efficiency, and resilience. Technological adoption, workforce development, policy alignment, and integration with public health initiatives further enhance the discipline's impact, while persistent challenges underscore the need for ongoing adaptation, innovation, and evidence-based policy support.

The global perspective reveals that while the foundational principles of family medicine are consistent, their operationalization is highly context-dependent. High-income countries often emphasize chronic disease management, preventive services, and interprofessional coordination,

whereas low- and middle-income countries frequently integrate broader public health responsibilities, including infectious disease management, maternal and child health, and community engagement. Cultural, economic, and systemic factors influence both the feasibility and the effectiveness of family medicine interventions, necessitating adaptable, context-sensitive models of practice. Comparative analyses indicate that lessons can be drawn from cross-national experiences, particularly regarding workforce training, policy support, technological integration, and community engagement strategies, offering pathways for improving the discipline globally.

The results and discussion demonstrate that family medicine is a multidimensional, dynamic, and strategically essential discipline within integrated primary health care. The synthesis of empirical evidence, theoretical frameworks, and global practices underscores its capacity to improve health outcomes, enhance equity, strengthen health system resilience, and respond adaptively to emerging challenges. Continuity, comprehensiveness, coordination, patient-centeredness, and integration with health systems and public health initiatives emerge as central pillars of effective practice, while workforce, policy, and technological considerations shape the discipline's potential for impact. The findings provide a robust foundation for identifying best practices, informing policy, guiding workforce development, and shaping future directions, reinforcing the centrality of family medicine as a cornerstone of twenty-first-century primary health care.

The extended analysis of family medicine as a cornerstone of integrated primary health care highlights the evolving scope, multidimensional impact, and emergent challenges that shape the discipline globally. Beyond the core principles of continuity, comprehensiveness, coordination, and patient-centeredness, the expanded literature demonstrates that family medicine increasingly functions as a strategic interface between clinical care, public health, social policy, and technological innovation. In this regard, the discipline operates not only as a provider of first-contact medical services but also as a mediator of systemic integration, a facilitator of health promotion, and a driver of equity and resilience across diverse populations and health system contexts. These findings underscore the argument that family medicine cannot be conceptualized solely as a clinical specialty but must be recognized as a dynamic, adaptive, and systemically essential component of twenty-first-century health care.

The impact of family medicine on chronic disease management remains one of the most consistently reported outcomes in the literature. Family physicians are uniquely positioned to manage complex patient presentations characterized by multimorbidity, polypharmacy, and psychosocial complexity. The results indicate that longitudinal relationships between patients and family physicians enable proactive monitoring, early intervention, and individualized care planning, all of which reduce complications, hospitalizations, and mortality. Studies from high-income countries highlight structured chronic disease management programs led by family physicians, incorporating standardized protocols, multidisciplinary collaboration, patient education, and digital monitoring tools. These interventions not only improve disease control but also enhance patient self-efficacy and adherence to treatment regimens. In low- and middle-income countries, family physicians frequently serve as primary coordinators for multiple disease burdens, managing both communicable and non-communicable conditions. Here, the role of family medicine extends beyond clinical care to encompass community-based prevention, population health surveillance, and integration with public health initiatives, demonstrating the discipline's adaptability and strategic relevance in resource-constrained environments.

Mental health care emerges as a significant area of expansion and impact within family medicine. Evidence indicates that family physicians often serve as the first point of contact for patients experiencing mental health concerns, including depression, anxiety, substance use disorders, and stress-related conditions. The integration of mental health assessment, counseling, and referral mechanisms within family medicine practices improves early identification, timely intervention, and ongoing monitoring. Patient-centered approaches, which emphasize empathetic

communication, shared decision-making, and social contextualization of symptoms, enhance treatment adherence and outcomes. Moreover, family physicians frequently bridge gaps between mental health services and primary care, coordinating with specialists, community support networks, and social services. The literature demonstrates that this integrative approach reduces stigma, improves access, and enhances the overall effectiveness of mental health interventions, reinforcing the discipline's holistic, patient-centered orientation.

Preventive care represents another critical domain in which family medicine demonstrates measurable impact. Studies consistently show that family physicians are instrumental in promoting immunizations, cancer screening, cardiovascular risk reduction, lifestyle interventions, and health literacy initiatives. By leveraging longitudinal relationships and trust, family physicians are able to tailor preventive recommendations to individual risk profiles, cultural contexts, and socioeconomic circumstances. Evidence suggests that populations with robust access to family medicine experience higher uptake of preventive services, lower rates of preventable diseases, and reduced healthcare expenditures. Preventive care delivered through family medicine also contributes to population-level health outcomes, addressing health inequities and enhancing life expectancy. Importantly, the integration of preventive services within the broader primary care framework ensures that these interventions are not isolated or episodic but rather continuous and coordinated, reflecting the core principles of comprehensive care.

Technological innovation plays an increasingly prominent role in augmenting the capabilities of family medicine. Digital health tools, electronic health records, telemedicine platforms, and mobile health applications facilitate enhanced monitoring, patient engagement, and care coordination. Telehealth, in particular, has proven effective in extending access to rural or underserved populations, enabling real-time consultations, remote monitoring, and follow-up care. Predictive analytics and artificial intelligence-based decision support systems provide family physicians with actionable insights for risk stratification, early detection, and personalized treatment planning. Despite these advantages, the literature identifies challenges associated with digital adoption, including disparities in access to technology, concerns regarding data privacy and security, potential depersonalization of care, and the need for physician digital literacy. The integration of technology must therefore be carefully balanced with the relational and ethical principles that define family medicine, ensuring that patient-centered, culturally competent, and holistic care remains central to practice.

The workforce dimension is a central determinant of family medicine's effectiveness, scope, and sustainability. Global evidence indicates that well-trained, adequately distributed, and professionally supported family physicians enhance health system performance, improve health outcomes, and reduce inequities. Structured education and training programs, standardized curricula, continuing professional development, and accreditation mechanisms are critical to ensuring competency, consistency, and credibility. The literature highlights innovative training models that integrate clinical practice with community engagement, health systems literacy, interprofessional collaboration, and research competence. Such training equips family physicians to navigate complex clinical scenarios, address social determinants of health, and assume leadership roles within health systems. Conversely, shortages of trained family physicians, maldistribution in rural or underserved areas, and limited professional recognition compromise continuity, accessibility, and comprehensiveness of care, emphasizing the need for strategic workforce planning and policy support.

Policy and governance structures significantly influence the implementation, effectiveness, and sustainability of family medicine. Comparative analyses reveal that countries with supportive policies prioritizing primary care, allocating resources strategically, and recognizing the centrality of family physicians achieve superior outcomes in terms of access, continuity, quality, and equity. Payment models aligned with long-term patient care, preventive interventions, and care

coordination incentivize practice behaviors consistent with the principles of family medicine. Conversely, fragmented financing, undervaluation of primary care, and inadequate policy support undermine the discipline's potential impact. International collaboration, advocacy, and knowledge exchange have proven effective in promoting policy environments conducive to family medicine, demonstrating the interplay between professional agency, systemic structures, and global health governance.

Social determinants of health and cultural contexts further shape the practice and impact of family medicine. The literature emphasizes that patient health outcomes are influenced by economic status, education, occupation, environment, and social support networks. Family physicians are uniquely positioned to address these determinants through community engagement, advocacy, and the integration of social services into care planning. Cultural competence, empathy, and communication skills enhance patient engagement, adherence, and trust, particularly in diverse populations. The results indicate that family medicine practices that incorporate socio-cultural awareness achieve improved health outcomes, higher patient satisfaction, and reduced disparities, reinforcing the discipline's ethical and relational dimensions.

Community engagement and public health integration are increasingly recognized as core functions of family medicine. Family physicians contribute to vaccination campaigns, screening programs, health education initiatives, disease surveillance, and preventive interventions at the population level. Evidence suggests that the integration of clinical and public health responsibilities strengthens health system responsiveness, fosters community trust, and enhances equity. Family medicine thus operates at the interface of individual care and population health, translating evidence into practice while addressing systemic barriers and social determinants of health. This dual role underscores the discipline's strategic significance in achieving universal health coverage, promoting health equity, and enhancing system resilience in the face of demographic, epidemiological, and environmental challenges.

Global comparative analysis demonstrates variation in the operationalization of family medicine principles across different health system contexts. In high-income countries, the emphasis is often on chronic disease management, technological integration, quality improvement, and interprofessional coordination. In contrast, low- and middle-income countries frequently position family physicians as primary providers for a broader spectrum of health concerns, including maternal and child health, infectious diseases, and community-based preventive care. Despite these differences, the core principles of continuity, comprehensiveness, coordination, and patient-centeredness remain consistent, highlighting the adaptability and universality of the discipline. Lessons drawn from cross-national experiences emphasize the importance of context-sensitive models, strategic workforce planning, policy alignment, and investment in training and infrastructure to optimize the effectiveness of family medicine globally.

Equity and access emerge as critical outcomes influenced by the integration of family medicine into primary health care. Evidence indicates that robust family medicine systems reduce disparities in health care utilization, improve access to preventive and curative services, and enhance outcomes for vulnerable populations. Continuity and comprehensiveness enable early identification and management of health risks, particularly for marginalized or underserved groups, while care coordination ensures timely referral and integration with specialized services. These findings align with theoretical frameworks emphasizing the social, ethical, and population health dimensions of family medicine, highlighting its role as a lever for achieving equitable and sustainable health systems.

Resilience of health systems is increasingly recognized as a function enhanced by family medicine. Longitudinal patient relationships, coordinated care networks, community engagement, and preventive strategies contribute to system adaptability, preparedness, and continuity during crises such as pandemics, natural disasters, or resource constraints. Family physicians serve as stabilizing

agents, maintaining essential services, providing guidance to communities, and facilitating information flow across levels of care. The literature indicates that countries with strong family medicine infrastructure experience lower system disruptions, more effective response to emergent health challenges, and sustained delivery of high-quality care. This reinforces the theoretical proposition that family medicine functions not only as a clinical specialty but also as a strategic system-level resource essential for population health and health system sustainability. Challenges persist in optimizing the impact of family medicine, including workforce shortages, insufficient infrastructure, limited policy support, and increasing complexity of patient needs. The growing prevalence of multimorbidity, aging populations, and social complexity imposes cognitive and organizational demands on family physicians. Addressing these challenges requires integrated approaches combining workforce development, policy support, interprofessional collaboration, technological innovation, and community engagement. The results indicate that systems that strategically address these factors demonstrate improved health outcomes, greater efficiency, and enhanced physician satisfaction, highlighting the interdependence of structural, professional, and systemic determinants in optimizing family medicine's contribution.

The expanded roles of family physicians, encompassing leadership, research, advocacy, and health system development, are increasingly evident in the literature. Family physicians contribute to health policy formulation, program evaluation, and knowledge generation, bridging the gap between practice, research, and governance. By engaging in research and data-driven decision-making, family physicians enhance evidence-based practice, inform health system reforms, and support population health interventions. Leadership within interprofessional teams, community health initiatives, and educational programs further expands the discipline's influence, reinforcing its centrality in integrated primary health care and its contribution to sustainable health system performance.

Technological innovation emerges as a transformative enabler for the discipline, with digital health platforms, telemedicine, electronic health records, wearable monitoring devices, predictive analytics, and artificial intelligence expanding the capacity of family physicians to deliver personalized, data-informed, and responsive care. The integration of these technologies facilitates remote access, chronic disease management, risk stratification, early intervention, and enhanced patient engagement, particularly in resource-limited or geographically dispersed populations. However, these advancements necessitate thoughtful governance, attention to ethical considerations, digital literacy, and safeguards to maintain patient privacy, equity, and relational continuity. The trajectory of family medicine indicates that technology will augment, rather than replace, the humanistic and relational dimensions that are foundational to effective, ethical, and patient-centered care.

The evidence synthesized throughout this article underscores the necessity for a multi-pronged, evidence-informed approach to advancing family medicine globally, emphasizing interventions at the clinical, educational, policy, technological, workforce, and research levels. Strategic recommendations must prioritize the enhancement of integrated primary health care while ensuring that family medicine remains adaptive, equitable, patient-centered, and responsive to emerging health challenges. First, health systems should invest in strengthening the infrastructure, capacity, and accessibility of family medicine services to ensure continuity, comprehensiveness, and coordination of care. This includes prioritizing primary care in national health policies, ensuring sufficient allocation of resources for facilities, equipment, and personnel, and implementing financing models that incentivize preventive care, longitudinal management, and multidisciplinary collaboration. Sustainable investment in infrastructure will facilitate equitable access for underserved, rural, and marginalized populations, addressing persistent health disparities and reinforcing the ethical and social imperatives of family medicine.

Workforce development represents a critical domain for strategic intervention. Educational institutions and professional bodies must ensure that family medicine training programs are comprehensive, competency-based, and aligned with contemporary health system needs. Curricula should integrate interprofessional education, systems thinking, health policy literacy, digital health competencies, leadership, and community-based experiential learning. Continuous professional development programs should provide avenues for skill enhancement, exposure to emerging technologies, research participation, and engagement in population health initiatives. Workforce policies should prioritize equitable distribution, retention incentives, career progression opportunities, and professional recognition, particularly in regions experiencing shortages or geographic maldistribution of family physicians. By fostering a skilled, motivated, and contextually prepared workforce, health systems can ensure that family medicine maintains its central role in delivering high-quality, coordinated, and equitable care.

The integration of technology into family medicine practice is essential to enhancing efficiency, accessibility, and quality of care. Policymakers and health system administrators should support the adoption of telemedicine, electronic health records, wearable devices, predictive analytics, and decision-support systems. However, implementation must consider ethical, legal, and practical dimensions, including data privacy, algorithmic transparency, patient consent, equitable access, interoperability, and digital literacy for both clinicians and patients. Training programs should incorporate digital competency as a core component, preparing family physicians to leverage technology effectively while preserving relational continuity, patient-centered care, and cultural sensitivity. Strategic deployment of technology can enhance chronic disease management, preventive interventions, mental health support, and community engagement, contributing to improved population health outcomes and system resilience.

Policy frameworks must prioritize family medicine as a central pillar of health systems, integrating it within governance structures, financing models, and health system design. Governments should establish policies that reinforce the strategic value of family medicine, incentivize evidence-based practice, support workforce sustainability, and facilitate coordination across sectors and levels of care. International collaboration, knowledge exchange, and adherence to global best practices can inform national strategies, enabling the adaptation of successful models while respecting local socio-cultural and economic contexts. Policies should also address social determinants of health, environmental exposures, and inequities, empowering family physicians to implement interventions that extend beyond clinical care and contribute to societal well-being. By embedding family medicine within broader health system priorities, policymakers can ensure that it functions as both a clinical and strategic instrument for sustainable, equitable, and high-performing health care.

Research and evidence generation are critical for advancing the discipline, guiding practice, and informing policy. Family physicians should be supported to engage in clinical research, health services research, implementation science, and population health studies. Investment in data infrastructure, research training, and collaborative networks will facilitate the production and translation of high-quality evidence into practice. Participatory approaches involving patients, communities, and interdisciplinary stakeholders should be encouraged to enhance the relevance, acceptability, and impact of research. Knowledge generated through these mechanisms can inform guidelines, policy decisions, and system innovations, ensuring that family medicine evolves in response to emerging health trends, technological advancements, and population needs. Global collaboration in research initiatives can foster the dissemination of best practices, promote capacity building, and strengthen the international recognition of family medicine as a dynamic and evidence-informed discipline.

Family medicine global and policy implications

The global implications of family medicine are multifaceted, reflecting the discipline's strategic significance across health systems, populations, and policy domains. As countries pursue the objectives of universal health coverage, equitable access, quality care, and system resilience, family medicine emerges as a critical lever for achieving these goals. Internationally, the integration of family physicians within primary health care frameworks has been consistently associated with enhanced health system performance, improved population health outcomes, and reduced disparities. Evidence from diverse regions demonstrates that strong family medicine infrastructure enhances continuity, comprehensiveness, coordination, and patient-centeredness, while simultaneously contributing to broader policy objectives such as health equity, preventive care, and system sustainability. The global discourse positions family medicine not only as a clinical specialty but also as a strategic component of health governance, capable of shaping policy, influencing resource allocation, and guiding system design.

Health policy frameworks at the national and international levels underscore the centrality of family medicine in achieving population health objectives. The Alma-Ata Declaration of 1978 established primary health care as a fundamental human right and recognized the provision of comprehensive, accessible, and community-oriented services as essential to equity and social justice. Family medicine operationalizes these principles, providing longitudinal, holistic care that integrates preventive, curative, rehabilitative, and palliative interventions. Subsequent global initiatives, including the Millennium Development Goals and the Sustainable Development Goals, have reinforced the importance of primary health care in achieving health equity, reducing morbidity and mortality, and addressing social determinants of health. In this context, family medicine serves as both an instrument and an enabler of policy objectives, translating global imperatives into locally actionable, evidence-informed interventions that address individual and population health needs.

International comparative studies reveal substantial variability in the integration and impact of family medicine, reflecting differences in governance, financing, cultural context, workforce, and infrastructure. High-income countries typically exhibit well-established family medicine systems characterized by structured training programs, robust policy support, advanced technological integration, and comprehensive service delivery models. These countries demonstrate measurable improvements in chronic disease outcomes, preventive care uptake, patient satisfaction, and health system efficiency. In contrast, low- and middle-income countries often face challenges related to workforce shortages, limited infrastructure, fragmented financing, and variable policy prioritization, constraining the reach and effectiveness of family medicine. Nevertheless, these countries also demonstrate innovative approaches, including community-based primary care models, task-shifting strategies, telehealth adoption, and integration with public health programs, which highlight the adaptability and contextual relevance of family medicine across diverse global settings.

Financing models represent a critical dimension of global and policy implications. Evidence indicates that health systems which prioritize primary care funding, incentivize longitudinal and preventive care, and align payment structures with family medicine principles achieve superior health outcomes, reduced costs, and enhanced equity. Capitation models, blended payment systems, and performance-based incentives have been associated with improved chronic disease management, preventive care delivery, and care coordination. Conversely, systems that undervalue primary care, rely heavily on fee-for-service models, or fail to recognize the longitudinal and coordination roles of family physicians encounter inefficiencies, fragmentation, and inequitable access. Global analyses highlight the necessity of aligning financing mechanisms with the operational principles of family medicine to maximize the discipline's impact, ensuring

that resources are directed toward interventions that enhance continuity, comprehensiveness, coordination, and population health.

Workforce policy constitutes another central consideration with global and systemic implications. The effective deployment of family physicians requires strategic planning that addresses training capacity, distribution, retention, professional recognition, and continuing professional development. Evidence indicates that countries with structured family medicine education programs, accredited curricula, and comprehensive professional support achieve higher workforce competency, system integration, and population health impact. Maldistribution of physicians, particularly in rural and underserved regions, remains a persistent challenge, necessitating policy interventions such as targeted incentives, community-based training, telehealth support, and interprofessional collaboration. Workforce policies that prioritize family medicine development not only enhance access and quality but also contribute to system resilience, ensuring continuity of care, preparedness for emergent health challenges, and sustainable population health improvements.

The integration of family medicine within health system governance structures is essential for optimizing policy impact. Family physicians often serve as intermediaries between communities, health system administrators, and policymakers, providing critical insights into population health needs, service gaps, and operational challenges. Governance mechanisms that include family physicians in decision-making processes, policy formulation, and quality improvement initiatives enhance the responsiveness, adaptability, and accountability of health systems. Furthermore, family medicine's integration with regulatory frameworks, professional associations, and accreditation bodies ensures that standards of care, ethical principles, and professional competencies are maintained, reinforcing system trust, patient safety, and quality outcomes. Global comparisons highlight that countries with inclusive governance structures, supportive regulatory environments, and professional engagement achieve more effective implementation of family medicine principles, underscoring the interdependence of policy, governance, and practice.

Equity and access emerge as fundamental global implications of family medicine. Evidence consistently demonstrates that strong family medicine infrastructure reduces health disparities, improves preventive care uptake, and enhances access for vulnerable populations. Longitudinal relationships between family physicians and patients facilitate the identification of social, economic, and environmental determinants of health, enabling targeted interventions that address inequities. Policies that support universal access to family medicine services, particularly for marginalized groups, enhance health equity, improve outcomes for children, women, the elderly, and individuals with chronic or complex conditions, and reduce avoidable hospitalizations. These findings underscore the ethical and policy imperative to prioritize family medicine as a central instrument for advancing social justice and equitable health systems globally.

Technological and digital health integration presents both opportunities and policy challenges with international significance. Telemedicine, electronic health records, digital health applications, and artificial intelligence have transformed the capacity of family physicians to provide accessible, coordinated, and data-informed care. Evidence demonstrates that technology facilitates real-time monitoring, chronic disease management, mental health support, preventive care engagement, and continuity of care, particularly in resource-limited or geographically dispersed populations. However, policy frameworks must address barriers related to digital literacy, equitable access, data security, privacy, interoperability, and ethical considerations. Global and national policies that strategically incorporate digital health into family medicine practice enhance efficiency, reach, and system resilience, while maintaining the relational and patient-centered ethos that underpins the discipline.

The public health dimension of family medicine further emphasizes its global and policy relevance. Family physicians serve as critical links between clinical care and population health, contributing to disease prevention, health promotion, surveillance, and community engagement. Policy initiatives that integrate family medicine into national public health strategies enhance vaccination coverage, early detection of communicable and non-communicable diseases, health education, and lifestyle interventions. Comparative evidence indicates that countries with strong family medicine-public health integration demonstrate improved health outcomes, reduced morbidity, and enhanced responsiveness to public health emergencies. This dual role of family medicine—delivering individual clinical care while advancing population health objectives—reinforces its strategic importance in global health policy, highlighting the need for coordinated planning, resource allocation, and system-level alignment.

Global health emergencies, such as pandemics, natural disasters, and humanitarian crises, further illustrate the policy implications of family medicine. Family physicians provide continuity of care, community-based interventions, early detection of outbreaks, risk communication, and coordination with public health authorities, contributing to system resilience and adaptive capacity. Policy frameworks that recognize and support the emergency response role of family medicine enhance preparedness, mitigate service disruption, and maintain essential health services. Evidence from recent global health crises demonstrates that countries with robust primary care systems anchored by family medicine experienced lower mortality, better disease control, and faster recovery, emphasizing the strategic value of the discipline in emergency preparedness and health security.

Research, knowledge generation, and evidence-based policy represent additional dimensions of global significance. Family physicians contribute to clinical, health systems, and population health research, generating data that inform policy, guide resource allocation, and shape practice guidelines. Policies that encourage research engagement, data sharing, and interprofessional collaboration enhance the knowledge base, ensure contextually relevant interventions, and strengthen the evidence-informed implementation of family medicine principles. Global initiatives, such as collaborative research networks, capacity-building programs, and international conferences, facilitate the dissemination of best practices, lessons learned, and innovative models, promoting continuous improvement and adaptation of family medicine worldwide.

Cultural and contextual factors further shape the global policy implications of family medicine. Health systems operate within diverse sociocultural, economic, and political environments, influencing the implementation, effectiveness, and acceptance of family medicine models. Policies that recognize and accommodate cultural practices, community norms, and local health beliefs enhance patient engagement, adherence, and satisfaction. Evidence indicates that culturally competent family medicine practices, supported by policy and professional frameworks, achieve superior health outcomes, foster trust, and reduce disparities. This underscores the necessity for policymakers to consider contextual realities when designing, implementing, and scaling family medicine programs, ensuring both efficacy and equity.

Workforce retention, motivation, and professional development represent critical policy considerations with global relevance. Evidence indicates that family physicians require supportive work environments, opportunities for career advancement, recognition of professional contributions, and access to continuing education to sustain high-quality care delivery. Policies that address remuneration, work-life balance, professional recognition, and career pathways enhance recruitment, retention, and performance, particularly in underserved or rural areas. Comparative studies demonstrate that countries with supportive workforce policies achieve greater continuity of care, improved system integration, and enhanced patient outcomes, highlighting the interdependence of human resource strategies and system-level policy planning in optimizing family medicine's impact.

Sustainability and health system resilience constitute further policy-relevant dimensions of family medicine. Evidence indicates that family medicine strengthens health system adaptability by promoting preventive care, reducing avoidable hospitalizations, coordinating services, and addressing social determinants of health. Policies that prioritize primary care, integrate family medicine into health system planning, and allocate resources for sustainable workforce development enhance the capacity of health systems to respond to demographic transitions, epidemiological shifts, and environmental challenges. In a global context characterized by aging populations, increasing prevalence of chronic disease, and emergent health threats, family medicine represents a durable, scalable, and strategically essential component of sustainable health system design.

The global and policy implications of family medicine underscore its centrality as both a clinical discipline and a strategic system-level instrument. Evidence demonstrates that family medicine enhances continuity, comprehensiveness, coordination, patient-centeredness, equity, system resilience, and population health outcomes across diverse contexts. Policy frameworks, financing mechanisms, workforce strategies, technological integration, cultural competence, and public health integration collectively determine the effectiveness, reach, and sustainability of family medicine. Globally, the discipline functions as a bridge between individual patient care, community health, health system governance, and international health objectives, reinforcing its strategic relevance in achieving universal health coverage, equitable access, and sustainable health systems in the twenty-first century. The synthesis of empirical evidence, theoretical frameworks, and global practice experiences highlights actionable policy levers, strategic priorities, and governance approaches to strengthen family medicine worldwide, ensuring that the discipline continues to adapt, innovate, and fulfill its foundational role in integrated primary health care.

Conclusions

- The comprehensive analysis presented in this article affirms that family medicine remains a central and indispensable pillar in advancing integrated primary health care across diverse health system contexts. Grounded in principles of continuity, comprehensiveness, coordination, and patient-centeredness, family medicine provides a coherent and sustainable framework for addressing the increasingly complex health needs of populations. As health systems worldwide confront demographic aging, the rising prevalence of chronic and multimorbid conditions, and persistent health inequities, the strategic importance of family medicine becomes even more pronounced. The findings underscore that integrated primary health care cannot be effectively realized without a strong, well-supported family medicine foundation embedded within health system design and governance.
- From a conceptual perspective, family medicine functions not merely as a clinical specialty but as a system-level integrator that bridges preventive, curative, rehabilitative, and palliative care across the life course. Its holistic orientation enables the alignment of individual patient care with population health objectives, fostering continuity and responsiveness while mitigating fragmentation. The synthesis of theoretical frameworks and empirical evidence demonstrates that family medicine contributes substantially to improved health outcomes, enhanced patient satisfaction, and more efficient utilization of health system resources. These contributions reinforce the argument that family medicine is essential to achieving equitable, accessible, and high-quality primary health care.
- Policy and governance emerge as decisive determinants of the effectiveness and sustainability of family medicine. Health systems that prioritize primary care investment, implement supportive financing mechanisms, and integrate family physicians into policy and decision-making processes consistently demonstrate superior performance. Conversely, fragmented policies, insufficient

workforce planning, and undervaluation of primary care services undermine the capacity of family medicine to fulfill its expanded roles. The conclusions highlight the necessity for coherent policy alignment that recognizes family medicine as a strategic asset, supports workforce development, and incentivizes longitudinal, preventive, and coordinated care models aligned with integrated primary health care principles.

- Global trends further illustrate the adaptive and evolving nature of family medicine. The expanding involvement of family physicians in chronic disease management, mental health care, preventive services, and public health initiatives reflects the discipline's capacity to respond to emerging population health challenges. Technological innovations, including telemedicine and digital health platforms, have enhanced access, continuity, and coordination of care, particularly in underserved settings. However, these advancements must be implemented thoughtfully to address digital inequities, ethical considerations, and the preservation of the relational aspects of care that define family medicine. The balance between innovation and humanistic practice remains critical to sustaining the discipline's effectiveness and social legitimacy.
- Looking forward, the long-term advancement of integrated primary health care through family medicine depends on sustained investment in education, research, and professional development. Training programs must equip family physicians with competencies in systems thinking, interprofessional collaboration, digital health, leadership, and evidence-based practice. Research engagement and knowledge generation are essential for informing policy, guiding system reforms, and ensuring contextually relevant care models. Strengthening these domains will enhance the resilience, adaptability, and credibility of family medicine in the face of evolving health system demands.
- The family medicine represents both a strategic necessity and a foundational element of integrated primary health care in the twenty-first century. By aligning conceptual frameworks, policy environments, global trends, and long-term strategic planning, health systems can leverage family medicine to improve population health outcomes, reduce inequities, and enhance system sustainability. The evidence synthesized in this study reinforces the enduring relevance of family medicine and provides a robust foundation for future policy, research, and practice aimed at strengthening integrated primary health care globally.

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RESULTS OF SURGICAL TREATMENT OF HIRSCHSPRUNG'S DISEASE IN CHILDREN

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Relevance. Surgical correction of Hirschsprung's disease in children is one of the most complex and relevant problems in pediatric surgery. Significant progress in addressing this condition has been achieved over recent decades due to the introduction of high-technology surgical treatment methods. However, despite improvements in many operative techniques and approaches, the rate of unsatisfactory functional outcomes in the long-term postoperative period remains as high as approximately 30% among all operated patients.

Aim. To improve and implement minimally invasive surgical methods for the treatment of rectal and rectosigmoid forms of Hirschsprung's disease in children.

Materials and Methods. From 2017 to 2025, 95 preschool-aged children with rectal and rectosigmoid forms of Hirschsprung's disease were treated as inpatients at the Pediatric Surgery Clinic of the Tashkent Pediatric Medical Institute. The patients were divided into two comparative groups. The first (control) group included 29 patients (30.5%) who underwent traditional open surgical procedures. The second (main) group consisted of 66 patients (69.5%) who underwent video-assisted transanal endorectal Swenson-like procedures with resection of the aganglionic segment.

Results and Discussion. A comparative analysis of surgical interventions for rectal and rectosigmoid forms of Hirschsprung's disease was performed based on a differentiated approach to the selection of corrective methods and techniques. Traditional open surgical procedures were carried out using the Soave–Lyonushkin method in 17 patients (17.9%) and the O. Swenson method in 12 cases (12.6%). The rationale for choosing these open techniques was that, in preschool-aged children with rectal and rectosigmoid forms of Hirschsprung's disease, submucosal dissection can be performed relatively easily even in the presence of a long aganglionic segment of the colon.

Minimally invasive video-assisted transanal endorectal procedures with resection of the aganglionic segment of the colon for rectal and rectosigmoid forms of Hirschsprung's disease were performed using the Swenson-like method in 18 patients (18.9%) and the De La Torre–Mondragón technique in 48 patients (50.5%).

Conclusion. The conducted studies clearly demonstrate that in the treatment of rectal and rectosigmoid forms of Hirschsprung's disease in children, preference should be given to minimally invasive transanal endorectal pull-through techniques, as they are less traumatic, more tissue-sparing, and more effective in terms of radicality and physiological appropriateness of the intervention. Traditional extensive open surgical procedures are characterized by greater technical complexity, insufficient functional outcomes, and comparatively poorer immediate and long-term results, often necessitating repeated surgical corrections and prolonged rehabilitation measures.

TACTICS OF SURGICAL TREATMENT FOR HIRSCHSPRUNG'S DISEASE IN YOUNG CHILDREN

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INTRODUCTION. Hirschsprung's disease is one of the most common congenital disorders of the colon in children and requires mandatory surgical treatment. Despite significant progress in pediatric surgery, the problem of choosing the optimal surgical strategy and method of operative intervention remains relevant. The incidence of postoperative complications and functional disorders necessitates further improvement of surgical approaches.

MATERIALS AND METHODS. The study included 41 patients with rectal and rectosigmoid forms of Hirschsprung's disease who were treated at the Department of Pediatric Surgery of the Multidisciplinary Children's Clinic of Tashkent State Medical University during the period from 2020 to 2025. All children underwent transanal endorectal proctoplasty according to the De La Torre–Mondragón technique with resection of the aganglionic segment. Diagnosis was based on the analysis of complaints, medical history, clinical findings, and the results of radiographic, ultrasonographic, and laboratory investigations.

RESULTS AND DISCUSSION. Surgical intervention was predominantly performed in young children, which is associated with more favorable anatomical and functional conditions for transanal demucosation. In most cases, good and satisfactory functional outcomes were observed. The early postoperative period proceeded without severe complications. In the long-term follow-up, anastomotic stenosis was detected in 3 patients and was successfully managed using conservative methods.

CONCLUSION. Transanal endorectal proctoplasty according to the De La Torre–Mondragón method is an effective and safe surgical technique for the treatment of distal forms of Hirschsprung's disease in children. This method reduces surgical trauma, accelerates rehabilitation, and improves functional outcomes, making it a preferred option in clinical practice.

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TRANSANAL ENDIRECTAL SURGERY FOR HIRSCHSPRUNG'S DISEASE IN YOUNG CHILDREN

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ABSTRACT

The results of surgical treatment of 41 children with rectal and rectosigmoid forms of Hirschsprung's disease aged from 3 months to 18 years, who were hospitalized at the clinic of Tashkent Pediatric Medical Institute during the period from 2020 to 2025, were analyzed. The conducted studies allowed us to conclude that in the treatment of rectal and rectosigmoid forms of Hirschsprung's disease in young children, preference should be given to transanal endorectal pull-through procedures according to the De La Torre–Mondragón method with resection of the aganglionic segment of the colon, as this technique is less traumatic, tissue-sparing, and the most effective in terms of radicality and physiological appropriateness of the intervention.

Key words: Hirschsprung's disease, surgical treatment, De La Torre–Mondragón operation, children.

Hirschsprung's disease is one of the most common groups of proctological disorders in children and requires corrective surgical intervention. The incidence of Hirschsprung's disease ranges from 1:4,417 to 1:5,000 live births and shows no tendency toward decline. According to data from the European Surveillance of Congenital Anomalies published for the period 2011–2015, the incidence of Hirschsprung's disease is 404 per 10,000 live births. The prevalence of this disease in Uzbekistan has not yet been clearly established; however, statistical data indicate that approximately 200 children with Hirschsprung's disease undergo surgical treatment annually in the Republic [3, 6, 9, 12].

Despite the achievements in the treatment of children with Hirschsprung's disease, this problem remains far from fully resolved. This is largely due to the difficulty of accurately determining the level and extent of the affected segment of the colon during diagnostic evaluation. An important contributing factor is the lack of a unified approach to preoperative assessment, as well as to the choice of surgical tactics, methods, techniques, and the extent of primary surgical correction, which inevitably leads to various postoperative complications and functional disorders following radical intervention. A high rate of postoperative complications and dissatisfaction with the results of primary radical operations often result in fecal incontinence, anastomotic leakage or stenosis, and, in cases of repeated surgical interventions, cicatricial deformation of the anal canal. Regardless of the form of Hirschsprung's disease, colostasis and constipation, as well as the above-mentioned postoperative complications, hinder normal physical development in children [1, 2, 4, 5, 7, 8, 10, 11, 13].

All these factors collectively contribute to social maladaptation of patients and deterioration of their quality of life, necessitating the search for new ways to improve and refine existing surgical methods and techniques, as well as the appropriate implementation of

postoperative conservative therapy and rehabilitation in children with Hirschsprung's disease [14, 15, 16, 17].

Aim of the study. To improve the outcomes of surgical treatment of Hirschsprung's disease in young children.

Materials and Methods. From 2020 to 2025, 41 children aged from 4 months to 18 years with rectal and rectosigmoid forms of Hirschsprung's disease were hospitalized and treated at the Pediatric Surgery Clinic of the Tashkent Pediatric Medical Institute. All patients underwent endorectal proctoplasty using the De La Torre–Mondragón technique with resection of the aganglionic segment of the colon. Diagnosis of Hirschsprung's disease in children was based on careful collection of complaints and medical history, assessment of clinical manifestations, physical examination, and the results of imaging studies (radiography, ultrasonography, and computed tomography), as well as additional instrumental investigations. In addition, functional parameters, biochemical laboratory data, and general clinical findings were taken into account.

Results and Discussion. Endorectal proctoplasty according to the De La Torre–Mondragón method with resection of the aganglionic segment of the colon was performed in 41 patients, including those with rectal (37 patients) and rectosigmoid (4 patients) forms of Hirschsprung's disease. In our study, this surgical technique was predominantly applied in children of a younger age group, mainly under 5 years of age, since the key stage of the De La Torre–Mondragón procedure—transanal demucosation of the mucosa of the seromuscular cylinder of the rectum from the perineal approach—is technically more favorable in this age group. In older children, due to the prolonged course of the disease and pronounced changes in the rectal mucosa, complete transanal demucosation without traumatic difficulties is often not feasible and presents certain technical challenges.

Subsequently, the mucosa of the anal canal was dissected proximally up to the peritoneal reflection, followed by mobilization of the rectum and sigmoid colon to allow their pull-through via the anal canal. The colon was then transected above the aganglionic segment, beyond the dilated transitional zone, and a coloanal anastomosis was constructed.

The surgical outcomes of transanal endorectal proctoplasty according to the De La Torre–Mondragón method were predominantly assessed as good and satisfactory and were observed in almost all operated patients. Both the early postoperative period and follow-up observations demonstrated that the De La Torre–Mondragón technique is effective; however, it is not without certain drawbacks. In particular, pain during defecation for a limited period was observed in 9 cases. Positive outcomes included the absence of complaints, resolution or marked reduction of meteorism, absence of colonic stasis, restoration of intestinal motor-evacuatory function in the early postoperative period, minimization of pain intensity, and early mobilization of patients. In the postoperative period, all patients obligatorily received conservative therapy and rehabilitation measures. An important component of postoperative conservative treatment in children with Hirschsprung's disease was the administration of B-group vitamins, as well as combined preparations of vitamins A, C, and E and trace elements.

Long-term Results. Long-term outcomes of transanal endorectal proctoplasty according to the De La Torre–Mondragón method demonstrated that patients had regular bowel movements with the urge to defecate, showed weight gain, and did not exhibit signs of colostasis or constipation. However, anastomotic stenosis was detected in 3 (7.3%) of the 41 operated patients, which required a 10-day course of bougienage. The advantages of this method include the performance of surgery without laparotomic access, minimal trauma during mobilization of the sigmoid and rectum, the possibility of early postoperative rehabilitation, and good and satisfactory functional outcomes. Another important advantage of this intervention is the prevention of intra-abdominal and urogenital complications. Management of complications that occurred in the early and long-term postoperative periods was carried out comprehensively, with the use of

rehabilitation measures aimed at normalizing the function of the colon and the entire digestive tract.

Conclusion. Thus, in our observations, transanal endorectal proctoplasty according to the De La Torre–Mondragón method with resection of the colon for rectal and rectosigmoid forms of Hirschsprung’s disease in children demonstrated significant advantages over abdominoperineal proctoplasty techniques, primarily due to a marked reduction in the number of complications in both early and long-term follow-up periods, without the need for repeated reconstructive surgical interventions. Transanal endorectal proctoplasty according to the De La Torre–Mondragón method is a minimally invasive and more physiological procedure that does not require laparotomy, while mobilization and pull-through of the sigmoid and rectum are performed without trauma to the pelvic organs. The effectiveness of transanal endorectal pull-through and the prevention of postoperative complications depend on strict adherence to surgical technique, avoidance of twisting and tension of the pulled-through bowel, and ensuring adequate blood supply to prevent ischemia.

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ANESTHETIC MANAGEMENT IN ELDERLY PATIENTS: CLINICAL FEATURES, RISKS, AND OPTIMIZATION STRATEGIES

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Abstract

Background: Population aging has led to a growing number of elderly patients requiring anesthesia for surgical procedures. Age-related physiological changes, comorbidities, and altered pharmacological responses increase perioperative risks and complicate anesthetic management in this population.

Objective: This review aims to analyze current evidence on anesthetic management in elderly patients, focusing on clinical features, perioperative risks, and strategies for optimizing anesthetic care to improve safety and outcomes.

Methods: A narrative review of the literature was conducted using PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. Publications from 2005 to 2025 addressing anesthetic management, perioperative risks, and optimization strategies in patients aged 65 years and older were analyzed and synthesized qualitatively.

Results: Elderly patients exhibit significant cardiovascular, respiratory, renal, hepatic, and neurological changes that influence anesthetic risk. Altered pharmacokinetics and pharmacodynamics necessitate dose adjustment and individualized drug selection. Common complications include hemodynamic instability, respiratory depression, postoperative delirium, and cognitive dysfunction. Evidence supports the use of comprehensive preoperative assessment, multimodal and opioid-sparing anesthesia, careful intraoperative monitoring, and structured postoperative care to reduce complications and enhance recovery.

Conclusion: An individualized, physiology-based approach to anesthetic management is essential for improving perioperative safety and outcomes in elderly patients. Optimized anesthetic strategies tailored to aging-related vulnerabilities can reduce complications and support functional recovery.

Keywords: elderly patients; geriatric anesthesia; anesthetic management; perioperative risk; pharmacokinetics; pharmacodynamics; postoperative complications; optimization strategies

Introduction

Relevance of the study. Population aging is a global demographic trend that has led to a steady increase in the number of elderly and very elderly patients undergoing surgical interventions. Advances in medicine have significantly extended life expectancy, resulting in a growing proportion of patients aged 65 years and older who require anesthesia for elective and emergency surgical procedures. This demographic shift presents new challenges for anesthesiology, as age-related physiological changes substantially affect anesthetic management. Elderly and senile patients are characterized by reduced functional reserves of vital organs, altered pharmacokinetics and pharmacodynamics of anesthetic agents, and a high prevalence of chronic comorbid conditions such as cardiovascular, respiratory, renal, and neurological diseases (Turayeva, 2025). These factors increase the risk of perioperative complications, including hemodynamic instability, postoperative cognitive dysfunction, delirium, respiratory depression,

and prolonged recovery. Anesthetic care in this population requires an individualized approach that considers biological age, frailty, polypharmacy, and cognitive status. Inadequate anesthetic management may lead not only to increased perioperative morbidity and mortality but also to a decline in functional independence and quality of life after surgery (Sidorenko, 2018). Therefore, studying the specific features of anesthesia in elderly and very elderly patients is highly relevant for improving perioperative safety, optimizing anesthetic techniques, reducing postoperative complications, and enhancing recovery outcomes.

The aim of this article is to systematically analyze current evidence on anesthetic management in elderly patients, with a focus on age-related physiological changes, perioperative risks, and strategies for optimizing anesthetic care to improve clinical outcomes and patient safety.

This research seeks to address the following research questions:

1. What age-related physiological and functional changes most significantly influence anesthetic management in elderly and senile patients?
2. What are the most common perioperative anesthetic risks and complications associated with anesthesia in this population?
3. How do pharmacokinetic and pharmacodynamic alterations in older adults affect the selection and dosing of anesthetic agents?
4. What optimization strategies in preoperative assessment, intraoperative management, and postoperative care have demonstrated effectiveness in reducing complications and improving recovery outcomes in elderly patients?

The findings of this review contribute to a deeper understanding of the complexities of anesthetic care in elderly patients and provide a structured overview of risk factors and optimization strategies. From a practical perspective, the results may support anesthesiologists and perioperative teams in making informed clinical decisions, individualizing anesthetic approaches, and improving perioperative safety. From a scientific standpoint, the study highlights gaps in current research and outlines directions for future investigations in geriatric anesthesiology.

Methods

This study was conducted as a narrative review of the literature aimed at synthesizing and critically analyzing current evidence on anesthetic management in elderly patients. A narrative review design was selected due to the heterogeneity of study designs, patient populations, anesthetic techniques, and outcome measures in the existing literature, which limits the feasibility of quantitative meta-analysis. A comprehensive literature search was conducted in major international databases, including PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. The search included publications released between 2005 and 2025 to reflect both established concepts and recent advances in anesthetic care for elderly patients. Search terms were selected to correspond directly to the study theme and included combinations of the following keywords: *elderly patients, geriatric anesthesia, anesthetic management, age-related physiological changes, perioperative risks, pharmacokinetics, pharmacodynamics, postoperative complications, delirium, cognitive dysfunction, frailty, and optimization strategies*. Boolean operators (AND, OR) were applied to refine and combine search results. Additionally, reference lists of relevant articles and clinical practice guidelines were manually reviewed to identify further pertinent sources.

Results and Discussion

Clinical and physiological features of elderly patients relevant to anesthesia

The analysis of the reviewed literature demonstrates that aging is associated with progressive structural and functional changes in multiple organ systems that directly influence anesthetic management. Cardiovascular alterations, including reduced arterial compliance, diminished β -adrenergic responsiveness, and impaired baroreceptor sensitivity, were consistently

identified as key factors predisposing elderly patients to perioperative hemodynamic instability (Butterworth et al., 2018; Miller et al., 2020). These changes increase susceptibility to hypotension and bradycardia during both general and regional anesthesia. Respiratory system aging is characterized by decreased lung elasticity, reduced vital capacity, weakened respiratory muscles, and diminished ventilatory response to hypoxia and hypercapnia. Several studies reported that these factors significantly increase the risk of perioperative hypoventilation, atelectasis, and postoperative pulmonary complications in elderly patients (Hines & Marschall, 2018; Deiner & Westlake, 2019). In addition, age-related decline in renal and hepatic function was shown to impair drug metabolism and elimination, thereby prolonging the effects of anesthetic agents and increasing the likelihood of drug accumulation (Mangoni & Jackson, 2019).

Neurological changes, including reduced cerebral blood flow, neuronal loss, and increased blood–brain barrier permeability, were frequently associated with heightened sensitivity to anesthetic drugs and an increased risk of postoperative delirium and cognitive dysfunction (Evered et al., 2018; Berger et al., 2021).

Age-related pharmacokinetic and pharmacodynamic changes

The reviewed evidence indicates that aging substantially alters both pharmacokinetics and pharmacodynamics of anesthetic agents. Reduced total body water, increased body fat percentage, and decreased plasma protein binding were found to affect the distribution and duration of action of both intravenous and inhalational anesthetics (Miller et al., 2020). Lipophilic drugs, such as benzodiazepines and certain opioids, demonstrated prolonged elimination half-lives in elderly patients, contributing to delayed recovery and increased risk of respiratory depression (Butterworth et al., 2018).

Pharmacodynamic sensitivity to anesthetic agents was consistently reported to be increased in elderly patients, with lower minimum alveolar concentration (MAC) requirements for volatile anesthetics and reduced dose requirements for sedatives and hypnotics (Eger, 2019). Several studies emphasized that failure to adjust anesthetic dosing according to age-related changes significantly increased the incidence of adverse drug reactions and prolonged postoperative sedation (Deiner & Westlake, 2019).

Perioperative risks and anesthesia-related complications

Across the analyzed studies, elderly patients exhibited a higher incidence of perioperative complications compared to younger adults. Hemodynamic instability, postoperative respiratory insufficiency, and prolonged recovery were among the most frequently reported anesthesia-related complications (Hines & Marschall, 2018). Cognitive complications, particularly postoperative delirium and postoperative cognitive dysfunction, emerged as major concerns, with reported incidence rates ranging from 10% to 40%, depending on patient characteristics and surgical complexity (Evered et al., 2018; Berger et al., 2021). Frailty, polypharmacy, and pre-existing cognitive impairment were identified as significant predictors of adverse outcomes. Multiple studies highlighted that polypharmacy increases the risk of drug–drug interactions and unpredictable anesthetic responses, further complicating perioperative management (Mangoni & Jackson, 2019). Additionally, elderly patients were shown to be more vulnerable to postoperative functional decline, which may persist beyond hospital discharge and negatively affect quality of life (Deiner & Westlake, 2019).

Optimization strategies for anesthetic management

The reviewed literature consistently emphasized the importance of individualized anesthetic strategies to mitigate perioperative risks in elderly patients. Comprehensive preoperative assessment, including evaluation of comorbidities, functional status, frailty, and cognitive function, was identified as a critical component of safe anesthetic planning (Berger et al., 2021). Several studies supported the use of multimodal anesthesia and analgesia to reduce opioid consumption and minimize adverse effects (Butterworth et al., 2018). Intraoperative

optimization strategies included careful titration of anesthetic agents, use of depth-of-anesthesia monitoring, maintenance of hemodynamic stability, and avoidance of excessive sedation (Eger, 2019). Postoperative measures such as early mobilization, adequate pain control, delirium prevention protocols, and close monitoring of respiratory and cognitive function were shown to contribute to improved recovery outcomes in elderly patients (Evered et al., 2018; Deiner & Westlake, 2019).

To facilitate a structured synthesis of the reviewed evidence, the key findings were systematically categorized according to major clinical domains relevant to anesthetic management in elderly patients. Given the multidimensional nature of aging-related physiological changes and their impact on perioperative safety, a comparative analytical framework was applied to integrate data on clinical features, associated anesthetic risks, and corresponding optimization strategies. The results of this integrative analysis are summarized in Table 1, which provides an overview of the principal organ-system–related changes observed in elderly patients, their implications for anesthetic care, and evidence-based approaches aimed at reducing perioperative complications and improving clinical outcomes.

Table 1 - Summary of clinical features, risks, and optimization strategies in anesthetic management of elderly patients

Analytical domain	Key findings in elderly patients	Clinical implications for anesthesia	Optimization strategies	Key references (APA)
Cardiovascular system	Reduced arterial elasticity, impaired baroreceptor reflexes, decreased cardiac reserve	Increased risk of hypotension, bradycardia, hemodynamic instability during anesthesia	Careful titration of anesthetic agents, invasive or non-invasive hemodynamic monitoring, avoidance of rapid induction	Butterworth et al., 2018; Miller et al., 2020
Respiratory system	Decreased lung compliance, reduced ventilatory response, weakened respiratory muscles	Higher incidence of hypoventilation, atelectasis, postoperative respiratory complications	Lung-protective ventilation, cautious opioid use, early postoperative respiratory support	Hines & Marschall, 2018; Deiner & Westlake, 2019
Renal and hepatic function	Reduced renal clearance and hepatic metabolism	Prolonged drug action, risk of accumulation and toxicity	Dose adjustment, avoidance of long-acting agents, careful fluid management	Mangoni & Jackson, 2019
Central nervous system	Increased sensitivity to anesthetics, reduced cerebral reserve	Higher risk of postoperative delirium and cognitive dysfunction	Depth-of-anesthesia monitoring, avoidance of excessive sedation, delirium prevention protocols	Evered et al., 2018; Berger et al., 2021
Pharmacokinetics and pharmacodynamics	Altered drug distribution and increased pharmacodynamic sensitivity	Delayed recovery, increased adverse drug reactions	Reduced dosing, individualized drug selection, multimodal anesthesia	Eger, 2019; Miller et al., 2020
Frailty and comorbidities	High prevalence of multimorbidity and frailty	Increased perioperative morbidity and prolonged recovery	Comprehensive preoperative assessment, individualized anesthetic planning	Berger et al., 2021
Polypharmacy	Frequent use of multiple medications	Drug–drug interactions, unpredictable anesthetic responses	Medication review, minimization of perioperative drug burden	Mangoni & Jackson, 2019

The analysis summarized in Table 1 demonstrates that anesthetic management in elderly patients is influenced by a complex interaction of age-related physiological changes, comorbid conditions, and pharmacological factors. Cardiovascular and respiratory alterations emerge as the most critical determinants of intraoperative instability, necessitating careful monitoring and conservative anesthetic techniques. The decline in renal and hepatic function significantly affects anesthetic drug metabolism, reinforcing the need for dose reduction and avoidance of long-acting agents in elderly patients. Neurological vulnerability represents one of the most clinically significant challenges, as increased sensitivity to anesthetics is closely associated with postoperative delirium and cognitive dysfunction. The reviewed evidence consistently supports the use of depth-of-anesthesia monitoring and multimodal anesthesia approaches to mitigate these risks. Furthermore, frailty and polypharmacy act as amplifying factors that increase susceptibility to adverse outcomes, highlighting the importance of comprehensive preoperative assessment and individualized anesthetic strategies. The tabulated analysis confirms that

optimization strategies targeting physiological reserve, pharmacological sensitivity, and perioperative risk factors are essential for improving anesthetic safety and recovery outcomes in elderly patients.

To further clarify how different anesthetic approaches may influence perioperative risks and recovery profiles in elderly patients, the reviewed evidence was synthesized into a comparative table. Table 2 contrasts commonly used anesthesia techniques in geriatric practice, highlighting their typical indications, potential benefits, technique-specific risks, and optimization measures required to enhance safety and outcomes.

Table 2 - Comparison of anesthesia techniques in elderly patients: clinical effects, risks, and optimization approaches

Technique	Typical indications in elderly patients	Key advantages	Main risks in elderly patients	Optimization strategies	Key references (APA)
General anesthesia (GA)	Major abdominal, thoracic, vascular surgery; procedures requiring airway control or deep immobility	Full control of airway and ventilation; suitable for complex/long surgery; stable surgical conditions	Hemodynamic instability (hypotension/bradycardia); postoperative respiratory depression; higher vulnerability to delirium/POCD; delayed recovery due to drug sensitivity	Age-adjusted dosing and slow titration; depth-of-anesthesia monitoring; lung-protective ventilation; multimodal analgesia to minimize opioids; careful temperature and fluid management	Butterworth et al., 2018; Eger, 2019; Evered et al., 2018; Miller et al., 2020
Neuraxial anesthesia (spinal/epidural)	Lower limb orthopedic surgery; urologic/gynecologic procedures; selected abdominal surgery; postoperative analgesia (epidural)	Reduced systemic anesthetic exposure; effective analgesia; decreased opioid need; potential reduction in pulmonary complications	Sympathetic blockade → hypotension; bradycardia; risk of high spinal block; urinary retention; contraindications with anticoagulants/common antiplatelet therapy	Preload/vasopressor strategy; incremental dosing (especially epidural); careful block height control; strict anticoagulation timing; ultrasound/technical optimization; postoperative monitoring for hypotension and urinary retention	Butterworth et al., 2018; Hines & Marschall, 2018; Miller et al., 2020
Peripheral nerve blocks (PNB)	Upper/lower limb surgery (e.g., hip/knee/shoulder); analgesia for fractures; ambulatory surgery	Strong opioid-sparing effect; improved early mobilization; potentially fewer respiratory complications; often better hemodynamic stability than neuraxial	Local anesthetic systemic toxicity (LAST); nerve injury (rare); falls due to motor weakness; masking compartment syndrome signs (selected contexts)	Ultrasound guidance; weight- and age-adjusted local anesthetic dosing; monitoring for LAST; fall-prevention protocols; integrate with multimodal analgesia; early physiotherapy planning	Butterworth et al., 2018; Hines & Marschall, 2018

Monitored anesthesia care (MAC) / sedation	Short diagnostic/interventional procedures; endoscopy; minor surgery with local anesthesia	Avoids full GA; potentially faster recovery; less airway manipulation	Oversedation → airway obstruction/hypoventilation; aspiration risk; hypotension; increased sensitivity to sedatives; delirium risk with deep sedation	Minimal effective sedation; capnography; avoid long-acting benzodiazepines; careful opioid titration; consider dexmedetomidine/short-acting agents where appropriate; clear discharge criteria	Deiner & Westlake, 2019; Mangoni & Jackson, 2019; Miller et al., 2020
Combined techniques (e.g., GA + regional)	Major orthopedic/abdominal surgery where analgesic optimization is required	Better pain control; reduced opioid requirements; smoother emergence; improved rehabilitation potential	Additive hypotension; block-related complications; need for coordinated monitoring and staffing	Protocolized pathways (ERAS-like); clear hemodynamic targets; standardized analgesic bundles; early mobilization and delirium prevention measures	Butterworth et al., 2018; Evered et al., 2018; Berger et al., 2021

The comparative analysis presented in Table 2 illustrates that no single anesthetic technique can be considered universally optimal for elderly patients; instead, the choice of anesthesia must be guided by surgical requirements, patient comorbidities, physiological reserve, and anticipated postoperative needs. General anesthesia remains indispensable for major and complex surgical procedures; however, the reviewed evidence consistently demonstrates that elderly patients exhibit heightened sensitivity to anesthetic agents, resulting in an increased risk of hemodynamic instability, respiratory depression, and delayed emergence (Butterworth et al., 2018; Miller et al., 2020). These findings underscore the necessity of age-adjusted dosing, careful titration, and the routine use of depth-of-anesthesia monitoring when general anesthesia is employed.

Neuraxial anesthesia offers significant advantages in selected elderly patients, particularly through reduced systemic exposure to anesthetic drugs and improved postoperative analgesia. Nevertheless, the pronounced sympathetic blockade associated with spinal and epidural techniques predisposes elderly patients to hypotension and bradycardia, which may be poorly tolerated in the presence of limited cardiovascular reserve (Hines & Marschall, 2018). The evidence suggests that incremental dosing strategies, vigilant hemodynamic monitoring, and strict adherence to anticoagulation guidelines are essential for minimizing complications related to neuraxial anesthesia in this population.

Peripheral nerve blocks emerge as a particularly valuable component of anesthetic management in elderly patients undergoing limb surgery, largely due to their opioid-sparing effects and favorable impact on early mobilization. Studies indicate that when ultrasound guidance and reduced local anesthetic doses are applied, the incidence of serious complications remains low, while functional recovery may be enhanced (Butterworth et al., 2018). However, the risk of falls related to motor blockade highlights the importance of postoperative safety protocols and interdisciplinary coordination. Monitored anesthesia care and procedural sedation represent suitable options for short or minimally invasive procedures, but Table 2 emphasizes that elderly patients are especially vulnerable to oversedation, airway compromise, and hypoventilation due to altered pharmacodynamics (Mangoni & Jackson, 2019). Continuous respiratory monitoring and avoidance of long-acting sedatives are therefore critical to maintaining safety in this context.

Combined anesthetic techniques, integrating general and regional approaches, demonstrate the potential to optimize analgesia while reducing opioid requirements and improving recovery trajectories. However, their successful application in elderly patients depends on structured perioperative protocols, clear hemodynamic targets, and coordinated postoperative care aimed at preventing delirium and functional decline (Evered et al., 2018; Berger et al., 2021).

The findings of this narrative review confirm that anesthetic management in elderly patients represents a complex clinical challenge driven by the interaction of age-related physiological changes, comorbid conditions, and altered pharmacological responses. Consistent with previous studies, the present analysis demonstrates that cardiovascular, respiratory, renal, hepatic, and neurological alterations significantly modify anesthetic risk profiles and require tailored perioperative strategies (Butterworth et al., 2018; Miller et al., 2020). One of the most important observations emerging from this review is the central role of cardiovascular vulnerability in elderly patients. Reduced arterial compliance, impaired autonomic regulation, and limited cardiac reserve markedly increase susceptibility to perioperative hypotension and bradycardia, particularly during induction of general anesthesia and neuraxial blockade. These findings align with existing evidence emphasizing the need for gradual anesthetic induction, invasive or advanced non-invasive monitoring, and proactive hemodynamic management in elderly populations (Hines & Marschall, 2018). Respiratory system aging further compounds anesthetic risk by increasing the likelihood of hypoventilation, atelectasis, and postoperative pulmonary complications. The reviewed literature highlights that even modest sedative or opioid dosing may result in clinically significant respiratory depression in elderly patients due to reduced ventilatory responsiveness and weakened respiratory musculature (Deiner & Westlake, 2019). These observations reinforce current recommendations advocating lung-protective ventilation strategies, opioid-sparing analgesia, and enhanced postoperative respiratory surveillance.

Neurological outcomes represent another critical domain in geriatric anesthesia. The high incidence of postoperative delirium and postoperative cognitive dysfunction reported across studies underscores the heightened cerebral sensitivity of elderly patients to anesthetic agents (Evered et al., 2018; Berger et al., 2021). Importantly, the evidence suggests that depth-of-anesthesia monitoring, avoidance of excessive sedation, and structured delirium prevention protocols may substantially reduce cognitive complications and support functional recovery. Pharmacokinetic and pharmacodynamic changes associated with aging were shown to influence all phases of anesthetic care. Decreased clearance, altered drug distribution, and increased pharmacodynamic sensitivity necessitate careful dose adjustment and individualized drug selection. Failure to account for these changes was consistently associated with prolonged emergence, respiratory compromise, and adverse drug reactions (Mangoni & Jackson, 2019; Eger, 2019). The comparative analysis of anesthetic techniques presented in Table 2 further illustrates that no single approach is universally optimal for elderly patients. Instead, technique selection should be guided by surgical demands, patient frailty, comorbidities, and anticipated postoperative needs. Regional and peripheral nerve block techniques offer clear advantages in selected cases by reducing systemic drug exposure and opioid consumption; however, their application requires meticulous attention to dosing, monitoring, and postoperative safety measures. Combined anesthetic techniques appear particularly promising within enhanced recovery frameworks, provided that structured protocols and interdisciplinary coordination are in place (Evered et al., 2018; Berger et al., 2021). The findings support a paradigm of individualized, physiology-driven anesthetic management in elderly patients, moving beyond chronological age alone toward a comprehensive assessment of functional reserve, frailty, and cognitive vulnerability.

Conclusion

Anesthetic management in elderly patients requires a comprehensive and individualized approach that accounts for age-related physiological changes, altered pharmacokinetics and pharmacodynamics, and the high prevalence of comorbidities and polypharmacy. The reviewed evidence demonstrates that elderly patients are at increased risk of hemodynamic instability, respiratory complications, cognitive dysfunction, and prolonged recovery when anesthetic care is not appropriately adapted to their physiological characteristics. Optimization strategies encompassing thorough preoperative assessment, careful anesthetic technique selection, age-adjusted dosing, vigilant intraoperative monitoring, and structured postoperative care are essential for improving perioperative safety and clinical outcomes. Multimodal and opioid-sparing approaches, depth-of-anesthesia monitoring, and delirium prevention measures play a particularly important role in mitigating adverse outcomes. Future research should focus on developing standardized, evidence-based protocols tailored specifically to elderly patients and on identifying interventions that preserve functional independence and quality of life following surgery. Strengthening the integration of geriatric principles into anesthetic practice remains a critical priority in the context of global population aging.

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Artificial Intelligence in Clinical Transplantation: From Predictive Analytics to Precision Graft Management

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Abstract

The field of solid organ transplantation is currently navigating a pivotal transition from standardized, population-based clinical protocols to a highly individualized paradigm defined by precision medicine and computational intelligence. This report provides an exhaustive analysis of the integration of artificial intelligence (AI) and machine learning (ML) across the transplant continuum — from the optimization of organ allocation and real-time graft viability assessment to personalized immunosuppressive dosing and non-invasive monitoring. Evidence from major clinical registries in the United States and Europe, including the United Network for Organ Sharing (UNOS), Eurotransplant, and the International Society for Heart and Lung Transplantation (ISHLT), demonstrates that advanced ML architectures such as Random Survival Forests (RSF), Gradient Boosting Machines (GBM), and Deep Neural Networks (DNN) consistently surpass traditional scoring systems like the Model for End-Stage Liver Disease (MELD) and the Kidney Donor Profile Index (KDPI) in predictive accuracy for both waitlist mortality and long-term graft survival.¹ Furthermore, the emergence of normothermic machine perfusion (NMP) integrated with AI-driven metabolic profiling and mitochondrial injury markers, specifically Flavin Mononucleotide (FMN), offers a sophisticated mechanism to rehabilitate and utilize extended criteria organs, thereby addressing the critical global organ shortage.⁵ The report also examines the clinical implementation of automated dosing systems for tacrolimus, which have shown superior performance compared to clinician-guided adjustments in randomized trials.⁸ Finally, the analysis addresses the essential role of explainable AI (XAI) frameworks, such as SHAP and LIME, in ensuring algorithmic transparency, and contrasts the evolving regulatory landscapes of the U.S. Food and Drug Administration (FDA) and the European Union AI Act.⁹ This synthesis underscores the potential for AI to enhance graft patency, reduce procedural futility, and promote equitable access to life-saving interventions.

Introduction: The Technological Imperative in Transplantation

Solid organ transplantation represents one of the most complex interventions in modern medicine, requiring the coordination of surgical precision, immunological management, and ethical resource distribution. Despite decades of advancement in surgical techniques and immunosuppressive regimens, the field faces three primary crises: an acute shortage of donor organs, the high incidence of chronic allograft dysfunction, and the limitations of traditional, linear predictive models in managing high-dimensional clinical data.¹ The "Industrial Revolution 4.0," characterized by the interaction of cyber-physical systems and deep-learning algorithms, is now being localized within transplantation to address these challenges.¹⁴

The fundamental limitation of historical clinical scores — such as the Child-Turcotte-Pugh (CTP) or the initial MELD — is their inability to account for the non-linear, synergistic relationships between donor characteristics and recipient physiology.² AI and ML offer a solution by processing large-scale, multidimensional datasets — including genomic, proteomic, imaging, and real-time

physiological inputs — to support more informed, real-time decision-making.¹² As AI transitions from experimental to clinically indispensable, it is delivering measurable reductions in mortality and healthcare resource utilization across multiple specialties, with transplantation positioned at the forefront of this digital era.¹

The Paradigm Shift in Organ Allocation and Donor-Recipient Pairing

The central challenge in organ allocation is the optimization of both utility (maximizing successful outcomes) and equity (ensuring fair access).¹⁷ In the United States, UNOS manages this process via the UNet technology, while Eurotransplant coordinates similar efforts across eight European nations.¹⁹ Traditional systems rely on fixed, points-based rules that often fail to capture the dynamic progression of end-stage diseases.

Limitations of Traditional Scoring in Liver Transplantation

The MELD score, implemented in 2002 and refined to include sodium (MELD-Na) and later updated to MELD 3.0, has long been the gold standard for liver allocation.² However, research indicates that MELD scores are susceptible to therapeutic interventions and lack the predictive granularity needed for short-term mortality assessments.² MELD 3.0, while improving on MELD-Na by incorporating sex and albumin, still operates on a traditional statistical foundation:

$$MELD\ 3.0 = 1.33\ (\text{if female}) + [4.56\ln(\text{bilirubin})] + [0.82 \times (137 - Na)] - [0.24(137 - Na) \times \ln(\text{bilirubin})] + [11.14\ln(\text{creatinine})] + [1.85 \times (3.5 - \text{albumin})] - [1.83 \times (3.5 - \text{albumin})\ln(\text{creatinine})] + 6$$

Comparative studies demonstrate that ML-based models, such as Artificial Neural Networks (ANN), significantly outperform MELD-Na and MELD 3.0 in predicting 28-day and 90-day mortality for patients with acute decompensation of liver cirrhosis.³

Predictive Model	28-day Mortality AUROC	90-day Mortality AUROC	Comparison Significance
Machine Learning (ANN)	0.811	0.839	$p < .003$
MELD-Na	0.577	0.682	Baseline ³
MELD 3.0	0.600	0.703	Baseline ³

Advanced Matching and Simulation in Europe

In Europe, Eurotransplant has utilized simulation tools to quantify the impact of alternative allocation rules.¹⁷ These simulations have identified systematic disparities; for instance, women often have a lower chance of receiving a transplant due to smaller physical stature and anatomical constraints that fixed rules fail to adjust for.¹⁷ AI-driven models like the Optimal Prediction of Mortality (OPOM) offer an adaptive alternative to these fixed systems, evolving as they are exposed to real-time patient data and providing a more objective prioritization of candidates.²³

Lung and Heart Transplantation Outcomes

In heart and lung transplantation, where ischemia times are critically short, AI has revolutionized the assessment of donor suitability. Analysis of 29,364 lung transplant patients from the ISHLT registry revealed that Gradient Boosting Machines (GBM) could predict 1-year survival with an AUROC of 0.958 using only 10 pre-transplant factors.⁴ This demonstrates that ML can identify a minimal set of highly influential features — such as albumin levels and mean pulmonary artery pressure — to optimize resource efficiency.⁴

Real-Time Graft Viability Assessment and Precision Preservation

The introduction of Normothermic Machine Perfusion (NMP) has provided a unique window for

the objective assessment of organs outside the donor's body.⁵ Traditionally, organs were often discarded based on subjective criteria or the risk profile associated with "Extended Criteria Donors" (ECD).

AI-Driven Metabolic Profiling

NMP maintains organs at 37°C, supplying them with oxygen and nutrients, which enables the continuous monitoring of metabolic activity.⁵ AI algorithms integrate various viability criteria to predict post-transplant function with high specificity.

Parameter	Viability Indicator during NMP	AI/Biomarker Enhancement
Lactate Clearance	\leq within 2.5h	Real-time trend analysis predicts EAD risk ⁵
Bile Production	$>$ with pH $>$	Predicts biliary stricture development ⁵
FMN (Flavin Mononucleotide)	Marker of mitochondrial complex-1 injury	AUROC 0.94 for predicting 90-day graft loss ⁶
Aminotransferases	AST, ALT, LDH incline trends	Identifies hepatocellular necrosis early ⁵

A landmark prospective validation study demonstrated that measuring FMN in the perfusate during the first four hours of NMP could accurately predict graft loss, with high levels being independently associated with reduced graft survival.⁶ Furthermore, the implementation of FMN-based assessment correlated with a 44% reduction in the 90-day comprehensive complication index, potentially saving \$43k in post-transplant costs per patient.⁶

Reducing Futile Procurements in DCD

Donation after Circulatory Death (DCD) represents a significant source of organs, yet approximately 50% of such donations are cancelled because the donor does not die within the required 45-minute timeframe to preserve organ quality.⁷ Researchers at Stanford University developed a machine learning model that uses neurological, respiratory, and circulatory data to predict the time of death with greater accuracy than human experts, reducing "futile procurements" by 60%.⁷ This advance not only optimizes organ utilization but also alleviates the operational and emotional strain on transplant teams and families.

Precision Immunosuppression and Pharmacogenomic Integration

Post-transplant management requires a lifelong, delicate balance between preventing rejection and avoiding drug-induced toxicities such as nephrotoxicity, infection, and malignancy.⁸ Tacrolimus, a calcineurin inhibitor (CNI), remains the primary agent for maintenance immunosuppression, yet it possesses a narrow therapeutic window and significant inter-patient variability.⁸

Automated AI Dosing Systems

Standard clinical practice for tacrolimus dosing often involves trial and error during the critical first weeks post-transplant. A major study at UZ Leuven in Europe implemented an automated AI model directly into the electronic health record system to calculate daily doses.⁸ In a randomized trial of 293 patients, the AI-driven approach outperformed clinician judgment:

- AI calculations led to ideal blood levels more quickly and with fewer fluctuations.⁸
- Doctors followed the AI recommendations in more than 99% of cases.⁸
- The system utilizes a mathematical model that transitions from population-based data to

individual patient data over time, increasing accuracy as more results become available.⁸

The Role of Long Short-Term Memory (LSTM) Networks

For forecasting trough concentrations (C_0), deep learning models like LSTM have shown exceptional promise.²⁶ In a large study at UC San Diego Health, LSTM models achieved a mean absolute error of 1.880 ng/mL when predicting next-day tacrolimus levels.²⁶ These models integrate diverse features, including transplant organ type, diet, and drug interactions, to guide dosing and prevent both under- and over-dosing.²⁶

Pharmacogenetics and Biological Markers

The variability in drug metabolism is largely driven by genetic polymorphisms in the CYP3A5 and CYP3A4 genes.²⁷ Individuals with the *1 carrier genotype metabolize tacrolimus rapidly and require higher doses, whereas those with the CYP3A53/*3 genotype require lower doses to avoid toxicity.*²⁷ AI-powered algorithms are now integrating these pharmacogenomic profiles with dynamic clinical data to move beyond traditional trough-based approaches toward true precision dosing.²⁵

Non-Invasive Monitoring and Precision Graft Management

The current gold standard for monitoring graft health is the invasive biopsy, which is costly, painful, and associated with risks such as hemorrhage and organ damage.³⁰ AI is enabling a shift toward non-invasive alternatives.

AI-ECG and Cardiac Allograft Rejection

At the Mayo Clinic, researchers developed a deep-learning model to identify moderate or severe acute cellular rejection (ACR) using a standard 12-lead ECG (AI-ECG).³¹ The results of this retrospective and prospective work are summarized below:

Metric	AI-ECG Performance	Clinical Significance
AUROC (Retrospective)	0.84 (95% CI: 0.78 – 0.90)	Superior to GEP and dd-cfDNA ³¹
Sensitivity (Prospective)	100% (2/2)	Highly reliable for screening ³¹
Negative Predictive Value	100%	Safely rules out rejection ³¹
Potential Biopsy Reduction	41% (314/758)	Significant resource savings ³¹

The AI-ECG model could recognize subclinical ACR approximately one month before biopsy confirmation, suggesting a window for early intervention that was previously unavailable.³¹

Molecular Imaging and Multi-Omics

The synthesis of non-invasive biomarkers — such as donor-derived cell-free DNA (dd-cfDNA) and gene expression profiling (GEP) — with advanced imaging offers a comprehensive view of graft health.³² While dd-cfDNA is highly sensitive in detecting early graft injury, molecular imaging techniques (e.g., PET, SPECT) enable the visualization of immune responses within the organ.³² AI-driven digital pathology is also advancing, with models trained to detect rejection markers directly from histopathological images, identifying features in the tubulointerstitium that correlate with long-term graft loss.¹⁶

Explainability, Ethics, and the "Black Box" Challenge

The integration of complex AI models into clinical workflows is hindered by the "black box" problem, where the reasoning behind a prediction is opaque to the clinician.²³ This lack of

transparency can lead to skepticism and limit the adoption of potentially life-saving tools.

SHAP and LIME in Transplantation

Explainable AI (XAI) tools like Shapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME) are being used to provide clinicians with interpretable insights.⁹

- **SHAP:** Provides a global view of feature importance, showing how variables like albumin levels or cold ischemia time consistently impact the model's predictions.⁴
- **LIME:** Offers local interpretability by explaining an individual patient's risk, helping a physician understand why a specific 30-day readmission risk was flagged.⁹

XAI not only fosters trust but also helps identify and mitigate algorithmic bias, ensuring that the model is not relying on behavioral or cultural factors that could lead to unequal outcomes for marginalized populations.³⁵

Algorithmic Bias and Equitable Access

AI systems are only as objective as the data used to train them.³⁵ If training datasets underrepresent complex cases or diverse ethnic groups, the resulting algorithms may reinforce existing inequities.¹⁸ European legal frameworks, specifically those originating from the Council of Europe, mandate that innovative technologies must be available in an "equitable and timely manner".¹⁸ Delineating "algorithmic due diligence" is therefore essential to prevent the digitization of socio-political biases.¹⁸

Regulatory Pathways: A Transatlantic Comparison

As AI technologies mature, regulatory agencies in the U.S. and Europe have established distinct pathways for oversight.

The U.S. FDA's Total Product Lifecycle (TPLC) Model

The FDA favors a flexible, iterative approach to AI as a Medical Device (AIaMD). A core innovation is the Predetermined Change Control Plan (PCCP), which allows manufacturers to define future algorithm updates at the time of initial approval.¹¹ This enables continuous improvement without the need for repeated regulatory submissions, accelerating the pace of innovation for tools like autonomous dosing or monitoring systems.

The EU AI Act and High-Risk Classification

In contrast, the European Union has adopted a more structured, risk-tiered approach through the EU AI Act.¹⁰ Medical AI systems are generally classified as "High-Risk," triggering several requirements:

- **Strict Data Governance:** Training and validation datasets must be representative and unbiased.¹⁰
- **Human Oversight:** Mechanisms must be included to allow clinicians to intervene or override AI decisions.³⁸
- **Dual Conformity Assessment:** Manufacturers must ensure compliance with both the AI Act and existing medical device regulations (MDR/IVDR).¹¹

Regulatory Framework	US FDA	EU AI Act
Philosophy	Adaptive, iterative TPLC	Precautionary, risk-based ¹¹
Update Mechanism	PCCP (Predetermined Change Plans)	NB (Notified Body) approval for major changes ¹⁰
Bias Mitigation	Post-market monitoring RWE	Pre-market data quality requirements ¹¹
Market Entry	Centrally managed by FDA	Distributed via Notified Bodies ¹¹

The divergence between these approaches poses a challenge for global device developers. While the FDA’s model encourages rapid deployment, the EU’s formalized rules may provide a more predictable path for ensuring fundamental rights and ethical accountability.⁴¹

Future Outlook: Toward Personalised Allograft Management

The future of transplantation medicine lies in the seamless integration of AI across every stage of the patient journey.¹ Emerging trends include the use of large language models (LLMs) like GPT-4 to simulate transplant selection committees and the development of "digital twins" to forecast long-term outcomes based on multi-omics data.⁴¹ Innovations in 3D bioprinting and xenotransplantation are also being facilitated by AI-driven structural modeling and genomic editing.¹

For heart and lung transplantation, the next frontier is the development of non-invasive screening tools — such as image-based biomarkers of nutritional status from routine CT scans — to better predict candidate readiness and post-transplant survival.⁴⁵ In lung transplantation, identifying predictive autoantibodies through ML could enable a simple blood test for early identification of chronic lung allograft dysfunction (CLAD).⁴⁵

Conclusion

Artificial intelligence has transitioned from a theoretical research tool to a central component of clinical decision-making in transplantation. By analyzing high-dimensional datasets that exceed human cognitive limits, AI models provide superior accuracy in organ allocation, reduce the incidence of futile surgical interventions through precision viability assessment, and optimize long-term outcomes via personalized immunosuppression regimens. The evidence from major centers in the United States and Europe underscores that the integration of AI-ECG, NMP-FMN markers, and automated dosing systems can significantly reduce post-transplant complications and healthcare costs while addressing the critical organ shortage. However, the successful implementation of these technologies depends on maintaining algorithmic transparency through XAI and navigating the complex regulatory landscapes of the FDA and the EU. Ultimately, the synergy between human clinical expertise and computational precision will define the next era of transplantation medicine, ensuring that the scarce resource of donor organs is utilized with maximal efficacy and equity.

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REHABILITATION OF CANCER PATIENTS: CONTEMPORARY CONCEPTS AND APPROACHES TO PROBLEM SOLVING

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Annotation: This scientific and analytical publication describes modern directions of rehabilitation of cancer patients with various localization of the tumor process. The currently available methods of rehabilitation treatment and scientific directions that require further research to improve the quality of life of this contingent of patients are described. The use of a comprehensive program of medical rehabilitation in cancer patients will restore their vital conditions as much as possible and will optimize the processes of physical, psychological and social adaptation of these patients, which is the main task of oncology and rehabilitation today.

Key words: oncology, rehabilitation, physical medicine, neuromuscular electrical stimulation, physical, psychological and social adaptation, quality of life.

Today, high rates of incidence of malignant tumors and a priori aggressive treatment

methods and, often, the prevalence of the oncological process itself lead to disability, requiring rehabilitation measures. In this regard, such a section of clinical oncology as the rehabilitation of cancer patients must be on the same level with modern treatment, diagnosis and prevention of cancer [1,2].

It is important to especially emphasize that rehabilitation measures begin not after the patient develops various kinds of physical and psycho-emotional dysfunctions as a result of specialized treatment and (or) complications of the tumor process, but already from the moment the diagnosis of a malignant neoplasm is made. At the same time, patients registered with an oncologist often experience various kinds of functional disorders that affect their quality of life and ability to work. For example, physical disorders may include fatigue, decreased muscle strength, cognitive dysfunction, paraesthesia, or eating problems, while mental symptoms may include anxiety, depression, fear of relapse, or insomnia. In this regard, the role of rehabilitation doctors and the importance of specialists with the skills of professional assessment and therapy in oncology services in this situation can hardly be overestimated [3].

One of the important aspects of complex rehabilitation of cancer patients is the use of drug correction of the psycho-emotional state of cancer patients, which previously received little attention. It is clear that oncologists and rehabilitation specialists take on this difficult role, but in some, quite common cases, additional drug support for the patient's psyche is required [4,5].

Thus, Taiwanese researchers Cheng-Hsu Wang et al. [6] not only analyzed, but also proved that the need for psychotropic drugs depends on the nosological form of the tumor. They analyzed data from 35,137 cancer patients from Taiwan's National Health Insurance database over 2.5 years. Among those patients who survived for at least 6 months, every fifth (20.9%) used psychotropic drugs: patients were most often prescribed sedatives (14.3%), then antidepressants (5.5%), anxiolytics (3.6%) and antipsychotics (2.7%). Lung cancer, prostate cancer and oral cancer showed a statistically significant association with regular drug use during the first six months after diagnosis. And among patients who survived for at least 2.5 years, 4.8% still use psychotropic medications on a regular basis.

Catherine L. Granger et al. [7] found through a systematic review of articles using the electronic databases Medline, Cinahl, Embase, Scopus and Cochrane that despite evidence and existing guidelines for physical activity in patients with lung cancer, it is hardly implemented in clinical practice. This systematic review of the literature showed that the challenges of adequate physical rehabilitation of patients with lung cancer are multifaceted and involve various factors. These include patient-level factors such as symptoms, comorbidities, sedentary lifestyle, mood and fear, and environmental factors. These factors should be taken into account to determine and develop a treatment and rehabilitation program for these patients.

In addition, very little attention is often paid to the fact that the main moral burden when caring for cancer patients falls, of course, on their loved ones. And, unfortunately, according to Swedish researchers Ji J. et al. [8] spouses of cancer patients who provide care are at increased risk of coronary heart disease and stroke. This is necessary to know for the correct approach to correcting the psychological state of not only the patient himself, but also their relatives (family rehabilitation).

At the same time, Badr H. et al. [9] found a low level of self-efficacy and a high level of distress when independently caring for patients with advanced lung cancer. The authors, based on experimental studies in which 39 patients took part, developed a program to coordinate care and train care skills for such patients. The program was based on self-determination theory. Participants reported significant reductions ($p < 0.0001$) in depression, anxiety, and caregiving burden, increased caregiver competence, and caregiver autonomy to provide care compared to usual care.

Similar results were obtained in their study by Kim Y. et al. [10]. The authors note that the

difficulty of psychological adaptation of relatives in families in which there is a cancer patient and the lack of social support are the main predictors of the development of major depressive disorders, even 3 years after diagnosis. At the same time, programs for adaptation to long-term care are crucial for the possibility of long-term (5-year results were taken into account) active care for the patient.

In addition, El-Jawahri A. et al. [11] found that patients' inadequate perception of their prognosis regarding cancer affects many of their decisions about medical care. However, the relationships between prognostic perception, quality of life, and patient mood itself are not yet fully understood. They stated the fact that, although patients wanted to know detailed information about their illness, half incorrectly perceived the fact that the prognosis in their situation was favorable. Of the 50 patients included in the study, 38 (76%) wanted to know as many details as possible about their diagnostic procedures and treatments. However, 25 of 50 patients (50%) stated that their goal was to "cure cancer," and only 10 of 49 patients (20%) reported that they had completely "put their fate in the hands of their oncologist." Patients who accepted their illness as a death sentence reported lower quality of life ($p=0.005$) and higher levels of anxiety ($p=0.003$) compared to those who did not perceive themselves as terminally ill. The authors established a direct connection between accurate prognostic perception and the quality of life of patients. Therefore, interventions aimed at improving understanding of disease prognosis provide adequate psychosocial support for these people.

Any methods, as we all understand perfectly well, should be used to alleviate the condition of cancer patients and restore their well-being. Such methods include art therapy, which, of course, belongs to non-traditional methods of influence, but with a comprehensive program of restorative treatment it shows its effectiveness.

Lee J. et al. [12] decided to evaluate the effect of art therapy using paintings by famous artists on the manifestation of long-term chronic stress (distress) in cancer patients receiving radiation therapy. The level of anxiety, depression and symptoms associated with the manifestation of the cancer itself were assessed. The authors conducted a prospective study that included 24 cancer patients with various forms of malignant neoplasms who received radiation therapy. Art therapy took place in two parts, including 4 sessions of a famous painting course and 4 sessions of works of art of the creative generation; these sessions were held twice a week for four weeks. Distress was assessed using the Hospital Anxiety and Depression Scale (HADS), the Hamilton Depression Rating Scale (HDRS), and the Edmonton Symptom Assessment Scale (ESAS) at three assessment points: before the start of art therapy, after the fourth session, and then after the eighth session. art therapy. It was found that of the 24 patients included in the study, 20 patients (83%) completed all eight sessions. At the same time, the authors note a significant and even significantly significant decrease in indicators of depression and anxiety on all scales used in the study.

It should be noted that a number of nosological forms of malignant tumors and crippling surgical interventions used in these diseases, such as enucleation of the eye, removal of the obturator apparatus of the rectum, breast extirpation lead to the deepest physical, psychological and social disability of patients. Laryngeal cancer is one of these localizations of the oncological process.

A very interesting and important study on this subject was carried out by Millgård M., Tuomi L. [13]. The study aimed to investigate the short-term and long-term effects of voice rehabilitation in patients treated with radiotherapy for laryngeal cancer as measured by both the acoustic measure smoothed cepstral peak prominence (CPPS) and perceptual measures. A secondary aim was to investigate the relationship between acoustic and perceptual measures. In total, 37 patients received voice rehabilitation post-radiotherapy and 37 patients constituted the irradiated control group. Outcome measures were mean CPPS for connected speech and ratings

with the auditory-perceptual Grade, Roughness, Breathiness, Asthenia and Strain (GRBAS) scale. Outcome measures were analyzed 1 (baseline), 6, 12, and 24 months post-radiotherapy, where voice rehabilitation was conducted between the first two time-points. Additional recordings were acquired from vocally healthy participants for comparison. As a result, CPPS values of the voice rehabilitation group and vocally healthy group were not significantly different at 24 months post-radiotherapy. Ten out of 19 patients who received voice rehabilitation yielded a CPPS value above the threshold for normal voice 24 months post-radiotherapy, compared to 11 out of 26 in the irradiated control group. No statistically significant correlations were found between CPPS and perceptual parameters of GRBAS. Based on the results obtained, the authors conclude that voice rehabilitation for irradiated laryngeal cancer patients may have positive effects on voice quality up to 24 months post-radiotherapy. The relationship between CPPS and GRBAS as well as the applicability of CPPS for evaluation over several points of measurement needs to be studied further.

In their paper, Zhu X. et al. [14] emphasize that dysphagia is a common complication in patients with laryngeal cancer after surgery and radiotherapy. The aim of the study was to study the impact of swallowing training administered in combination with nutritional intervention on the nutritional status and quality of life of laryngeal cancer patients with dysphagia after surgery and radiotherapy. Sixty-six patients with laryngeal cancer who developed dysphagia were randomly divided into control group and intervention group (n = 33 in each group). Patients in both groups received total laryngectomy and prophylactic radiotherapy and were provided routine health counseling and swallowing training. Patients in the intervention group were additionally provided with nutritional intervention. All patients were evaluated using video fluoroscopic swallowing examination (VFSE), Patient-Generated Subjective Global Assessment on nutritional status (PG-SGA) score, and Quality of Life Questionnaire-core 30 (QLQ-c30) score immediately after radiotherapy and 3 months later. The results were as follows: prior to swallowing training, there was no significant between-group difference with respect to VFSE evaluation, PG-SGA score, or QLQ-c30 score. Both groups showed improvement in these measures at 3 months after radiotherapy; however, the improvement in the intervention group was significantly better than that in the control group. The researchers conclude that swallowing training combined with nutritional intervention can improve swallowing function, nutritional status and the quality of life of laryngeal cancer patients with dysphagia after operation and radiotherapy.

As noted by Salerno G. et al. [15], total laryngectomy represents the surgical procedure necessary for the treatment of some advanced neoplasms of the hypopharyngeal-laryngeal district and involves strong functional, physical and emotional repercussions. In their study, our colleagues examined how rehabilitation techniques used to improve the communication needs of patients who have undergone laryngectomy affect their perception of quality of life. The questionnaires "V-RQoL" and "SECEL" were administered to 45 patients divided into four groups on the basis of the type of vicarious voice: group TE (27 patients), group E (7 patients), group EL (2 patients), group NV (9 patients). Patients using electrical or tracheo-esophageal prostheses reported a better quality of life than patients with an erythromophonic voice. Regarding postoperative satisfaction, the group with esophageal voice was the most satisfied. The authors emphasize the importance of preoperative counseling to make the patient as aware as possible of his future condition.

Retinoblastoma is an intraocular cancer of infancy and childhood, which has been treated with radiation therapy and chemotherapy. Radiation on growing patients can cause deterioration in maxillofacial growth and development that leads to severe skeletal discrepancies between the maxilla and mandible, and dental problems such as crossbite, openbite, and hypodontia. Kim S.H. et al. [16] presented a case of a 19-year-old Korean man with chewing disability and dentofacial

deformities. He had undergone enucleation of the right eye and radiation therapy of the left eye due to retinoblastoma 100 days after birth. Subsequently, he received cancer therapy for the secondary nasopharyngeal cancer at the age of 11 years. He was diagnosed with severe skeletal deformity including sagittal, transverse, and vertical growth deficiency of the maxilla and midface, and with class III malocclusion, severe anterior and posterior crossbite, posterior openbite, multiple missing upper incisors, right premolars, and second molars, and impaction of the lower right second molars. To restore impaired functions and esthetics of the jaw and dentition, the orthodontic treatment combined with two jaw surgery was performed. At the end of surgical orthodontics, dental implants were placed for prosthetic treatment of missing teeth. Additional plastic surgery for zygoma elevation was done with calvarial bone graft followed by fat graft. Facial esthetics and occlusal functions of patient were favorably enhanced with the improvement of skeletal discrepancy and the rehabilitation of maxillary dentition by prosthetic work. At the 2-year follow-up, the skeletal and dental relationships and implant prosthetics were well maintained. The authors conclude as follows: in an adult patient with dentofacial deformities caused by early cancer therapy in the head and neck area, interdisciplinary interventions including additional plastic surgery of zygoma depression and prosthetic work of missing teeth as well as surgical-orthodontic treatment could establish favorable facial esthetics and oral rehabilitation.

The case of eyeball prosthetics was presented in their study by Goiato M.C. et al. [17]. Male patient, 60 years old, sought care at the Oral Oncology Center of the São Paulo State University "Júlio de Mesquita Filho", for the rehabilitation of the orbital cavity with an acrylic eye prosthesis. This prosthesis was made with thermopolymerizable acrylic resin and hand painted iris with oil paint on cardboard. The prosthesis was installed after finishing and polishing and the hygiene and general care instructions were explained. Colleagues focus on the fact that the lack of an eye has an immediate and long-term impact on a patient's life. In the present case, the patient was satisfied with the aesthetics and comfort of the prosthesis, which demonstrates the success of the treatment.

As Rokohl A.C. et al. [18] show, a smooth supply with a visually appealing prosthetic eye after enucleation is not just a cosmetic solution, it is also a key factor in successful social and psychological rehabilitation. The authors submitted an overview of the current state of medical and ocular care regarding prosthetic eyes in Germany. It focuses mainly on the newest clinical results, daily care, complications, and psychological aspects of wearing prosthetic eyes. As a result of the latest clinical data and a current review of the PubMed literature, it was found that in Germany, enucleated patients normally get a double-walled, hollow prosthetic eye made of cryolite glass, and patients with a microphthalmic or phthisic eye receive a thin single-walled prosthesis. Anophthalmic patients wearing cryolite glass prosthetic eyes seem to be more satisfied with their appearance and the look of their prostheses than polymethylmethacrylate (PMMA) prosthetic eye wearers. Cryolite glass prosthetic eyes must be renewed at least each year, while PMMA prostheses need to be polished once a year and renewed after five years of wearing. Among children, the fit of the prosthetic eye must be checked, based on growth, semi-annually. A slightly higher risk of breakage of cryolite glass prostheses is, for most patients, not a great disadvantage in everyday life. Ocularists and ophthalmologists should determine an individual cleaning regime, together with the patient, that is dependent on the material of the ocular prosthesis and other external factors. Complications, such as allergic, giant papillary, viral and bacterial conjunctivitis and blepharoconjunctivitis sicca must be treated at an early stage to allow for a prosthetic eye. In the case of inflammation-caused socket shrinkage or post-enucleation socket syndrome, surgical interventions are needed to re-enable the use of a prosthetic eye. Since the health of the remaining eye is the major psychological burden of prosthetic eye wearers, good ophthalmological care and medical screenings are essential elements. In conclusion, the researchers conclude that a smooth supply with a prosthetic eye, adequate and early treatment

of possible complications and attention to psychological aspects is essential for successful long-term rehabilitation of enucleated patients.

As well as patients with previous localizations of the oncological process, patients with colorectal cancer with colostomies need mandatory rehabilitation measures.

Thus, Yang P. et al. [19] set themselves the goal of to systematically evaluate the effect of collaborative nursing on self-care ability of postcolostomy patients with colorectal cancer (CRC). PubMed, Web of Science, Embase, China National Knowledge Infrastructure, and Wanfang databases were searched to collect relevant literatures on randomized controlled trials of postcolostomy patients with CRC. The search period was started from 2010 to 2021. Statistical analysis was performed on the data extracted from the comprehensive meta-analysis with STATA 16.0 analysis software. As a result, it was found that the incidence of adverse reactions in the control group was higher than that in the treatment group. Seven studies included the preintervention self-care concept and preintervention self-care skills. Six studies included preintervention self-care responsibility and preintervention exercise of self-care agency (ESCA) scale. In the comparison among the concept of self-care after intervention, self-care skills, self-care responsibility, and ESCA scale, all of them had higher scores in the treatment group than in the control group ($p < 0.05$). It fully explains that collaborative nursing can significantly improve the evaluation indicators of patients' self-care ability and reduce patient complications. In summary, the authors conclude that the application of collaborative nursing in the nursing work of patients with CRC after colostomy can significantly reduce the incidence of adverse nursing reactions.

The aim of the work is Yu S., Tang Y. [20] to explore the impacts of comprehensive care on psychological emotion, postoperative rehabilitation and complications of colorectal cancer patients after colostomy. From August 2018 to February 2020, a total of sixty colorectal cancer patients undergoing colostomy in our hospital were collected and randomly assigned to a control group to receive conventional care and a research group to receive comprehensive care, with 30 patients in each group. The two groups of patients were compared for postoperative recovery, complications, adverse psychological emotions, self-care ability, quality of life, and nursing satisfaction. The first time of exhaust, food intake and the recovery of bowel sound in the research group were markedly earlier than those in the control group. Besides, the research group had notably lower incidence of postoperative complications, lower self-anxiety scale (SAS) and self-depression scale (SDS) scores at discharge, and higher average self-care ability than the control group, as well as higher quality of life score and nursing satisfaction. At the end of the work, it was concluded that comprehensive care intervention can promote postoperative recovery of colorectal cancer patients after colostomy, relieve their negative emotions, reduce postoperative complications, improve quality of life and nursing satisfaction, which are all important and make this type of care worthy of promotion in clinical practice.

A study by Wang S.Y. et al. [21] examined the effects of a multimedia patient education intervention on improving self-care knowledge and skills in patients with colorectal cancer who underwent colostomy surgery. A quasi-experimental design was adopted to measure the self-care knowledge and skills of patients with colorectal cancer before and after surgery. The experimental group ($n = 33$) received a multimedia patient education intervention, whereas the control group ($n = 30$) was provided conventional instructions. Results were evaluated using analysis of covariance. On the day prior to discharge from hospital, the experimental group exhibited significantly greater improvement in self-care knowledge than did the control group. The experimental group also exhibited significantly greater improvement in self-care skills than did the control group on the day of gas passage, the day prior to discharge from hospital, and during the first clinic visit after discharge from the hospital. In other words, multimedia patient education intervention yielded greater improvement in self-care knowledge and skills than did conventional instruction. The authors state that multimedia patient education is an adequate educational tool

for patients with colorectal cancer who have undergone colostomy.

Now, regarding the rehabilitation of patients with breast cancer.

The leading method of treating malignant neoplasms, including breast cancer, is surgical. As Chan K.S. points out. et al. [22], functional results are increasingly important in breast cancer, as survival and prognosis for this pathology improve over the years. Since more than half of diagnosed breast cancer cases occur in middle-aged women between 45 and 64 years of age, it is appropriate to ensure preservation of upper extremity function as this group of patients may be the primary caregivers for their families, lead active lifestyles, and are at the peak of their careers. Additionally, most previous studies have shown that Asians may have higher body fat percentages, lower bone mass, and lower levels of physical activity than Western populations. These factors may influence functional outcomes in patients with breast cancer. The authors conducted a single-center prospective cohort study with a follow-up period of 6 weeks after surgery. The main inclusion criteria were patients over 21 years of age who underwent 44 radical surgical interventions - wide sectoral resection - 16 (36.4%) and mastectomy - 28 (63.6%). The main exclusion criteria were patients with pre-existing neurological or rheumatological comorbidities affecting upper limb function, or previous trauma that resulted in upper limb deformity. Patients who had undergone mastectomy with reconstruction were also excluded. The patients underwent early rehabilitation from the 1st day after surgery, including a standardized set of exercises for the shoulders and upper extremities. Active shoulder flexion and abduction range of motion and disability scores were assessed 1 week before surgery and then at weeks 2 and 6 postoperatively. This pilot study in an Asian cohort showed that patients were able to regain active range of motion of shoulder flexion and abduction at 6 weeks postoperatively, but had a worse disability score, especially in the axillary lymph node dissection subgroup after sentinel lymph node examination. Recommendations include the use of active early rehabilitation methods for breast cancer patients, however, as the authors note, longer follow-up is required to assess long-term functional results.

The modern direction in medical rehabilitation of patients with breast cancer, as well as in their treatment today, is the individualization of the treatment and rehabilitation program. As Olsson Möller U. et al. note in their publication [23], it is well known that women suffer from the negative consequences of breast cancer treatment and that their very important needs during rehabilitation interventions are often not met. At the same time, up to 43% of these women are at risk of developing chronic distress, requiring comprehensive treatment. However, it is unknown how to identify and meet the needs of these women early, leaving them with a low chance of optimal rehabilitation. The authors plan to conduct a three-arm randomized controlled trial and aim to develop a model and evaluate the effect of individualized screening-based rehabilitation after primary treatment for breast cancer. The rehabilitation program will be based on self-reported data, focusing on physical and psychological outcomes, as well as treatment satisfaction at baseline at 2 weeks, 3, 6, 9 and 12 months. The assessment will also include economic aspects of health, based on register data and information from patients and their relatives during the rehabilitation process. In addition, optimal threshold levels of negative behaviors will be explored as an indicator of the need for extended rehabilitation. It is planned to identify potential new problems and rehabilitation needs of patients during the 1-year follow-up period. The researchers note that this study will provide important knowledge regarding the effectiveness of screening to identify needs for individualized, standardized, evidence-based rehabilitation after primary breast cancer treatment.

Much work regarding the development of a rehabilitation program for patients with breast cancer has been carried out by Spanish scientists and clinicians Barnadas A. et al. [24]. As the researchers emphasize, the gradual increase in incidence associated with the aging population and the implementation of screening programs, together with lower mortality rates from breast

cancer, has led to an increase in the number of surviving patients with this pathology. The treatment used leaves physical, psychological and psychosocial consequences that can manifest and persist even years after completion of treatment and can interfere with the well-being of breast cancer patients and their reintegration into normal social and professional activities. Complications of the underlying disease and concomitant pathology require joint monitoring by specialized medical institutions and primary health care services. The authors have compiled guidelines aimed at ensuring joint and coordinated monitoring of these patients by these medical services. The guideline addresses health problems arising from treatment, with recommendations for a therapeutic approach that individualizes treatment, as well as suggestions for coordinated joint monitoring by primary and secondary care. In addition to organizational issues, the guide provides general recommendations for breast cancer patients: 1) avoid excess weight, 2) healthy diet and exercise, 3) quit smoking, 4) moderate alcohol consumption, 5) possible use of additional treatment methods, for example, such as acupuncture, 6) awareness of symptoms indicating a possible relapse or recurrent tumor, 7) adherence to prescribed anti-estrogenic hormone therapy for a long period (5-10 years), 8) return to work.

In addition, one of the modern methods of restorative treatment of cancer patients includes a method such as neuromuscular electrical stimulation (NMES) [25]. It may be a pragmatic short-term alternative to voluntary exercise in patients who are currently undergoing or have recently completed treatment for cancer. In this study, the authors assessed the impact of a personalized and progressive NMES exercise intervention, designed with the early rehabilitation period in mind, on patients' physical performance and quality of life. This manipulation was found to improve performance on the 30-second sitting test (STS), the 6-minute walking test (6 MW), and global quality of life using the EORTC QLQ C-30 questionnaire. Benefits gained included improved muscle strength and greater confidence when walking. The authors recommend further evaluation of this technique in a further controlled prospective study.

Wang Y. et al. [26] indicate that epidemiological studies consistently demonstrate an inverse association between physical activity levels and the risk of developing gynecological cancers, as well as improved survival outcomes among cancer survivors engaging in regular exercise. Mechanistic insights suggest that physical activity and exercise may modulate key pathways involved in carcinogenesis, tumor progression, and treatment response, offering promising avenues for preventive and adjunctive therapeutic interventions. However, despite a growing body of research in exercise oncology, there is a lack of disease-specific synthesis addressing how exercise can be tailored to the distinct pathophysiological, treatment-related, and psychosocial challenges of gynecological cancers. Current guidelines often generalize exercise recommendations across all cancer types, overlooking the unique symptom burdens, such as pelvic floor dysfunction, sarcopenia, and menopausal symptoms, specific to gynecologic malignancies. Beyond cancer-type-specific exercise programs, a significant aspect of survivorship care for gynecological cancer patients involves addressing psychosocial and functional needs that affect both physical and emotional well-being. Several interventions have sought to integrate exercise and rehabilitation programs with psychosocial support to help gynecologic cancer survivors better cope with treatment-related challenges and improve their overall quality of life. These programs aim not only to enhance physical fitness but also to address the emotional and psychological distress that often accompanies cancer treatment and recovery. These studies collectively emphasize that exercise interventions, when combined with psychosocial support, are crucial for improving physical health while also addressing the psychological and emotional burdens faced by gynecologic cancer survivors. Therefore, integrating flexible, behaviorally supported, and symptom-specific rehabilitation strategies into routine oncology care is essential to optimize both physical and mental health outcomes in these patients. By adopting a multidimensional research framework and addressing these gaps, the full therapeutic potential of

lifestyle interventions may be realized to improve clinical outcomes and survivorship. Emphasis should also be placed on advancing molecular and translational research to bridge mechanistic understanding with clinical application, thereby informing more precise and biologically grounded exercise prescriptions in gynecologic oncology.

In recent years, the term “multimodal” has been increasingly used in clinical research, which means, according to Wiktionary, involving or using several methods or modes of implementation. When analyzing a review of the literature related to multimodal rehabilitation of cancer patients, it should be noted that the overwhelming number of scientific works are devoted to the use of rehabilitation measures at the stage of preparing patients for specialized treatment, be it surgery or courses of drug or radiation therapy.

Guinan E.M. et al. [27] note in their work that the inflammatory changes themselves and the disruption of redox processes after radical surgery for esophageal cancer significantly affect both the quality of life and the survival of patients. In this regard, an integrated approach to the rehabilitation of these patients, including special exercises and a certain diet, can reduce the negative manifestations of the treatment. However, the authors note that the results will be further examined in a larger randomized controlled trial. In addition to the impact of these manifestations on the survival of patients, the economic side of the full rehabilitation of these patients will also be studied.

Bolshinsky V. et al. [28], based on an analysis of studies on multimodal rehabilitation programs before surgery for gastrointestinal tumors, conducted a systematic literature search using Medline, PubMed, Embase, Cinahl, Cochrane and Google Scholar databases. Study quality was assessed using the Cochrane Risk of Bias Tool (randomized trials) and the Newcastle-Ottawa Quality Assessment Scale (cohort studies). Of the 544 studies identified, 20 were included in the qualitative analysis. The authors found that although small studies have found encouraging results, larger prospective studies using uniform objective risk stratification and structured interventions with prespecified clinical and economic endpoints are needed to determine the definitive value of prehabilitation programs.

Summing up the analyzed works on rehabilitation measures in cancer patients with various nosological forms of malignant neoplasms, we can draw a definite conclusion that a multifaceted approach is required when conducting rehabilitation treatment in these patients, aimed at compensating for impaired body functions, improving the quality of life, reducing the severity of disability and prolonging active life. The process of recreating the vital status of patients is multidimensional and requires an integrated approach to restore the physical, psycho-emotional and social conditions of patients. At the same time, almost all authors agree on one thing: further multicenter randomized studies are needed to develop standardized approaches to conducting rehabilitation measures in cancer patients.

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Pedagogical Sciences

Social Practices of Women Teachers in China and Kazakhstan: Gender Asymmetry in the Scientific and Educational Space

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ABSTRACT

This paper provides an in-depth comparative study of the social practices of women teachers in higher education institutions in China and Kazakhstan, with particular attention to gender asymmetry within scientific and educational spaces. Although women constitute a numerical majority in teaching positions, their participation in academic leadership, high-level research, institutional governance, and policy-making remains disproportionately low. Drawing on a mixed-methods approach that combines large-scale survey data (N = 240), in-depth semi-structured interviews (N = 60), and institutional statistical records from eight representative universities, this study reveals persistent structural and cultural barriers shaping women's academic careers. Quantitative analysis demonstrates significant gender gaps in publication output, grant acquisition, promotion rates, and leadership representation. Structural equation modeling further identifies workload distribution, access to academic networks, mentoring opportunities, and institutional support as key mediating variables. Qualitative findings illustrate how gender norms, family expectations, and invisible labor intensify women's professional constraints. The study argues that gender inequality is reproduced through routine institutional practices rather than isolated discrimination. Policy recommendations emphasize gender-sensitive evaluation systems, transparent promotion mechanisms, leadership training, and long-term institutional accountability frameworks.

Keywords: Women teachers; gender asymmetry; higher education; comparative study; social practices; China; Kazakhstan.

INTRODUCTION:

Gender inequality in academia has emerged as a global concern, attracting increasing scholarly attention across sociology, education, and gender studies. Despite the expansion of higher education systems and policy commitments to gender equality, academic institutions continue to exhibit pronounced vertical and horizontal gender segregation. Women are disproportionately represented in teaching-intensive and lower-status academic roles, while men dominate senior professorial ranks, research leadership positions, and strategic decision-making bodies.

In China, the rapid modernization of higher education has significantly increased women's participation in academic employment. However, performance-based evaluation systems, publication pressures, and competitive funding mechanisms have intensified gendered inequalities. Similarly, Kazakhstan's post-Soviet higher education reforms have expanded access while reproducing hierarchical governance structures that marginalize women in leadership and

research-intensive roles. These parallel yet contextually distinct systems provide a valuable comparative lens for understanding how gender asymmetry is produced and maintained. This study adopts a social practices perspective, emphasizing everyday institutional routines, informal norms, and interactional processes through which inequality is normalized. By comparing women teachers' experiences in China and Kazakhstan, the research contributes to international debates on gendered academic labor, professional mobility, and the reproduction of inequality within knowledge-producing institutions.

LITERATURE REVIEW

Existing literature on gender and higher education highlights the persistence of gendered organizational cultures. Acker's theory of gendered institutions emphasizes how ostensibly neutral rules and procedures systematically privilege masculine career trajectories. Bourdieu's concept of social and cultural capital further explains how access to academic networks, symbolic recognition, and institutional legitimacy shapes career advancement.

Comparative studies demonstrate that women scholars face higher teaching loads, greater administrative responsibilities, and lower access to research resources. These constraints limit research productivity and reduce competitiveness for promotion and funding. Studies in Asian and post-Soviet contexts reveal that traditional gender norms, family expectations, and caregiving responsibilities intersect with institutional demands, producing cumulative disadvantages over time.

However, empirical comparative research between China and Kazakhstan remains limited. This study addresses this gap by integrating quantitative and qualitative evidence to examine how gender asymmetry operates across different institutional and cultural contexts.

METHODS AND METHODOLOGY:

A mixed-methods research design was employed to capture both structural patterns and lived experiences. Quantitative data were collected through standardized questionnaires administered to 240 women teachers, with 120 respondents from each country. The survey included variables related to age, academic rank, educational background, teaching workload, research output, grant participation, leadership roles, and perceptions of institutional support.

Qualitative data were obtained through semi-structured interviews with 60 women teachers (30 from each country). Interviews explored career trajectories, promotion experiences, work-life balance, informal networks, mentoring, and perceptions of gender bias. Institutional data were collected from official university documents, including faculty composition reports, promotion guidelines, and research performance indicators.

Quantitative analysis involved descriptive statistics, independent-sample t-tests, correlation analysis, and multivariate regression modeling. Structural equation modeling was used to examine indirect effects among key variables. Qualitative data were analyzed using thematic coding, enabling the identification of recurring narratives and cross-national similarities and differences.

4)RESEARCH MODEL:

The conceptual framework guiding this study links gender norms, workload allocation, access to academic resources, institutional support mechanisms, and career outcomes. Gendered expectations shape teaching responsibilities and service work, leading to reduced time for research activities. Limited access to academic networks and mentoring further constrains research productivity and leadership opportunities. These mechanisms collectively influence promotion trajectories and professional recognition.

Figure 1 presents the conceptual framework linking gender norms, workload allocation, access to academic resources, institutional support mechanisms, and career outcomes. The model

hypothesizes that gendered expectations shape professional responsibilities, which in turn influence research productivity, leadership opportunities, and promotion trajectories.

Table 1: illustrates the conceptual model linking gender norms, workload, academic resources, and career outcomes

Country	Mean Age	PhD (%)	Leadership (%)
China	38.4	41	23
Kazakhstan	40.2	34	19

TABLE 2: Research Productivity (Mean Publications)

China	3.8 articles/year
Kazakhstan	2.1 articles/year

Table 2 reveals a substantial cross-national gap in research productivity, with women teachers in China publishing approximately 81% more articles per year than their counterparts in Kazakhstan. This disparity reflects not only individual performance differences, but more importantly structural variations in institutional research ecosystems, including:

- Availability of research funding and grants
- Access to international journals and indexing systems
- Institutional incentives for publication
- Research infrastructure and administrative support
- National performance evaluation regimes

RESULTS:

Descriptive statistics indicate that women teachers in China have a higher average publication rate than those in Kazakhstan; however, leadership participation remains low in both contexts. Regression analysis reveals that workload intensity and limited access to academic networks are significant predictors of lower research productivity ($R^2 = 0.49$). Structural equation modeling confirms the mediating role of workload distribution and institutional support. Qualitative findings reveal that women frequently perform invisible labor, including student mentoring, administrative coordination, and emotional support, which is undervalued in evaluation systems. Respondents also report exclusion from informal research networks and decision-making processes, further limiting career advancement.

DISCUSSION:

The findings demonstrate that gender asymmetry in academia is sustained through interconnected structural and cultural mechanisms. Evaluation systems emphasizing quantitative research output fail to account for unequal workload distribution. Cultural expectations regarding

caregiving responsibilities further intensify gendered constraints. While national contexts differ, similar patterns of inequality emerge, highlighting the global nature of gendered academic structures.

Misalignment Between Evaluation Systems and Gendered Labor Realities

Current academic evaluation systems emphasize:

Publication quantity

Citation impact

Grant acquisition

POLICY IMPLICATIONS

To address gender asymmetry, higher education institutions must adopt gender-sensitive evaluation criteria that recognize teaching, service, and mentoring contributions. Transparent promotion mechanisms, leadership training programs for women, and institutional mentoring systems are essential. National policy frameworks should integrate gender equity indicators into university performance assessments.

CONCLUSION:

Gender asymmetry in scientific and educational spaces is structurally embedded within academic institutions, sustained through workload allocation patterns, evaluation regimes, informal power networks, and culturally gendered expectations.

This study demonstrates that women's lower visibility in leadership and research output does not reflect reduced competence, but rather systematically constrained opportunity structures.

By adopting a comparative lens between China and Kazakhstan, the research reveals that distinct national systems reproduce strikingly similar gender hierarchies, underscoring the global persistence of gendered academic stratification.

This research contributes to scholarship by:

Providing comparative empirical evidence on gendered academic careers in two under-researched contexts

Demonstrating how everyday institutional practices reproduce inequality

Integrating quantitative productivity data with qualitative lived experiences

Reframing women's academic disadvantage as a structural governance issue rather than an individual limitation

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LLM TECHNOLOGIES IN GENERAL SECONDARY EDUCATION: THEORETICAL CONCEPTS AND METHODOLOGICAL DIRECTIONS IN GEOGRAPHY EDUCATION

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Abstract

The rapid advancement of artificial intelligence has led to the widespread emergence of large language models (LLMs) as powerful tools in educational contexts. In recent years, LLM-based technologies have attracted growing attention due to their potential to support personalized learning, inquiry-based instruction, and the development of higher-order cognitive skills. However, despite increasing interest in their educational applications, the theoretical foundations and methodological directions for integrating LLM technologies into general secondary education remain insufficiently systematized, particularly within subject-specific domains such as geography. This review article aims to analyze the theoretical concepts and methodological approaches underpinning the use of LLM technologies in general secondary education, with a specific focus on geography teaching. Drawing on contemporary pedagogical theories—including constructivist, cognitive, socio-cultural, and inquiry-based learning frameworks—the study examines how LLM technologies align with modern educational paradigms and disciplinary characteristics of geography education. International and national scholarly sources are systematically reviewed and synthesized using a theoretical-analytical approach.

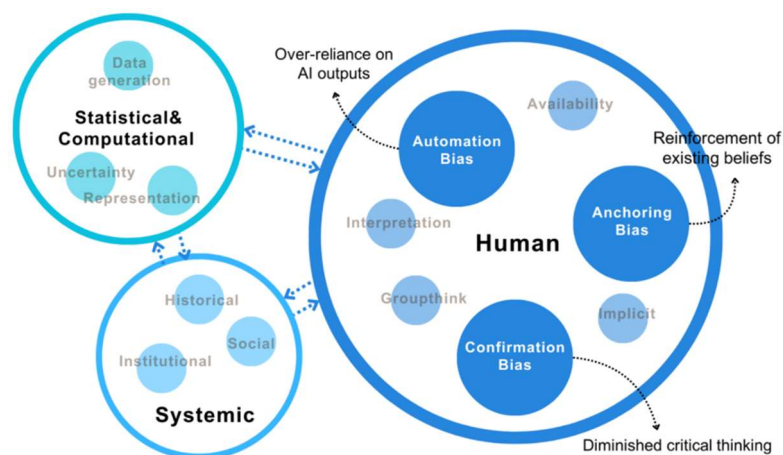
The analysis reveals that LLM technologies offer significant methodological potential for geography education by supporting learner-centered instruction, differentiated tasks, formative assessment, and the development of critical and creative thinking skills. At the same time, the review identifies key challenges related to curriculum alignment, age-appropriate adaptation, teacher professional competence, and ethical considerations in school settings.

The findings of this study contribute to the theoretical justification of LLM integration in school geography education and provide a conceptual basis for the development of subject-oriented methodological models and future empirical research.

Keywords: Large language models (LLMs); artificial intelligence in education; general secondary education; geography education; teaching methodology; digital pedagogy; inquiry-based learning; educational innovation.

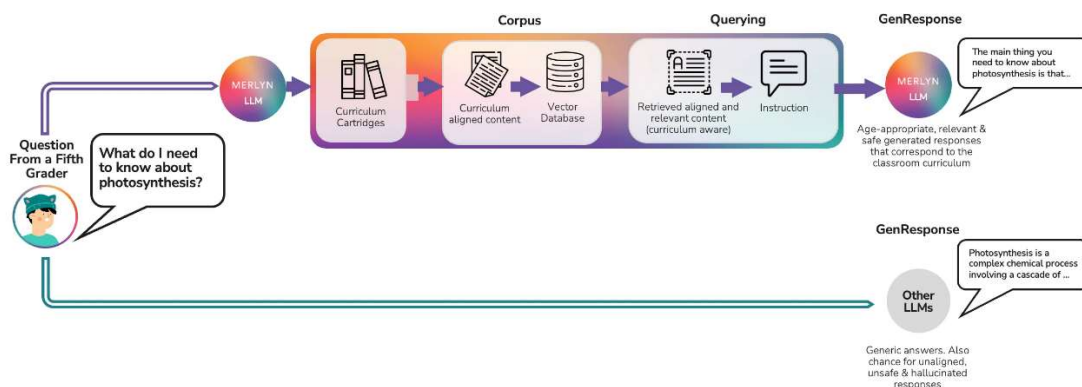
Introduction. The rapid advancement of artificial intelligence (AI) has significantly influenced contemporary educational research and practice, particularly through the emergence of large language models (LLMs). Recent studies emphasize that LLM-based technologies extend beyond traditional educational software by enabling natural language interaction, automated explanation, and cognitive scaffolding (Brown et al., 2020; Kasneci et al., 2023). Scholars argue that these models represent a new generation of educational tools capable of supporting personalized learning, inquiry-based instruction, and higher-order thinking when grounded in sound pedagogical principles (Holmes et al., 2019; Zawacki-Richter et al., 2019).

Within general secondary education, the integration of LLM technologies raises important methodological questions related to curriculum alignment, age-appropriate learning, and teacher mediation. Research by Holmes, Bialik, and Fadel (2019) highlights that AI tools in schools must be aligned with established learning theories to ensure meaningful educational outcomes. At the same time, Selwyn (2022) cautions against uncritical adoption of AI in classrooms, emphasizing the need for pedagogical oversight and professional judgment, particularly in secondary school contexts where learners' cognitive and ethical development remains in progress.



Geography education offers a particularly relevant disciplinary context for examining the pedagogical potential of LLM technologies. Geography combines spatial reasoning, textual interpretation, and problem-oriented inquiry, making it well suited to AI-supported learning environments (Lambert & Morgan, 2010; Butt, 2017). Recent research suggests that digital and AI-based tools can enhance geography teaching by supporting comparative regional analysis, explanation of complex human–environment interactions, and the development of critical geographic thinking (Favier & van der Schee, 2014; Schultz et al., 2022). However, most existing studies focus on GIS and spatial technologies, while language-based AI applications remain underexplored in school geography.

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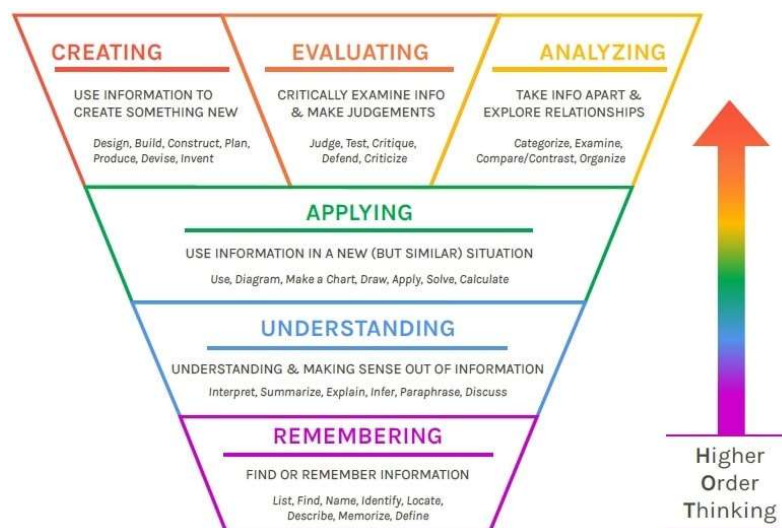
Against this backdrop, this review article aims to systematize the theoretical foundations and methodological directions for the use of LLM technologies in general secondary education,

with a specific focus on geography teaching. By synthesizing contemporary pedagogical theories and recent AI-in-education research, the study seeks to provide a concise conceptual framework for the pedagogically sound integration of LLMs into school geography curricula and classroom practice.

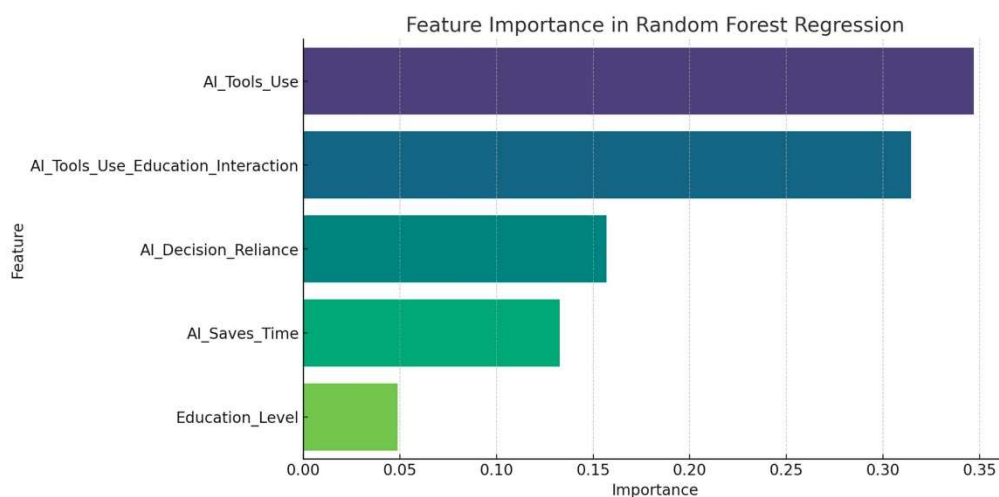
Literature Review. The growing body of literature on artificial intelligence in education increasingly emphasizes the pedagogical potential of large language models (LLMs) as advanced cognitive and instructional tools. Existing research can be broadly grouped into three interrelated strands: (1) studies on AI and LLM technologies in education, (2) research on subject-specific applications of AI in geography education, and (3) critical scholarship addressing pedagogical, ethical, and equity-related challenges of AI integration in secondary schooling.



The first strand focuses on the conceptualization of AI—and more recently LLMs—as instruments for supporting learning processes rather than merely automating instruction. Early work by Luckin et al. (2016) and Holmes et al. (2019) established foundational frameworks for understanding AI as a tool for personalized and adaptive learning. With the emergence of transformer-based LLMs, research attention has shifted toward their capacity to generate explanations, scaffold reasoning, and engage learners in dialogic interaction. Brown et al. (2020) demonstrated that large-scale language models exhibit emergent abilities in text generation and problem-solving, which has direct implications for educational use. Building on this, Kasneci et al. (2023) argue that LLMs should be viewed as cognitive partners that can support higher-order thinking, metacognitive regulation, and inquiry-based learning when embedded within sound pedagogical designs.



A second strand of literature examines the role of digital and AI-based technologies in geography education, emphasizing their contribution to spatial thinking, analytical reasoning, and inquiry-oriented learning. Geography has long been associated with the use of digital tools such as GIS, interactive maps, and spatial data visualization to analyze complex socio-environmental processes (Lambert & Morgan, 2010; Butt, 2017). Recent studies suggest that AI-enhanced tools can extend these practices by supporting textual interpretation of geographic phenomena, comparative regional analysis, and explanation of cause–effect relationships in human–environment systems (Favier & van der Schee, 2014; Schultz et al., 2022). Although most existing research focuses on GIS and spatial technologies, emerging scholarship indicates that language-based AI tools can complement spatial analysis by assisting students in formulating geographic arguments, interpreting narratives of place, and synthesizing multiple sources of geographic information.



The third strand addresses methodological and ethical challenges associated with the integration of LLM technologies in general secondary education. Researchers highlight concerns related to curriculum alignment, age-appropriate use, academic integrity, and teacher professional competence. Zawacki-Richter et al. (2019) emphasize that the educational value of AI depends on its grounding in pedagogical theory and disciplinary knowledge. Similarly, Selwyn (2022) cautions against techno-solutionist approaches, arguing that uncritical adoption of AI tools risks undermining educational goals and professional autonomy. International policy documents, including UNESCO (2023), stress the importance of ethical AI use in education, particularly with regard to transparency, bias, and equitable access.

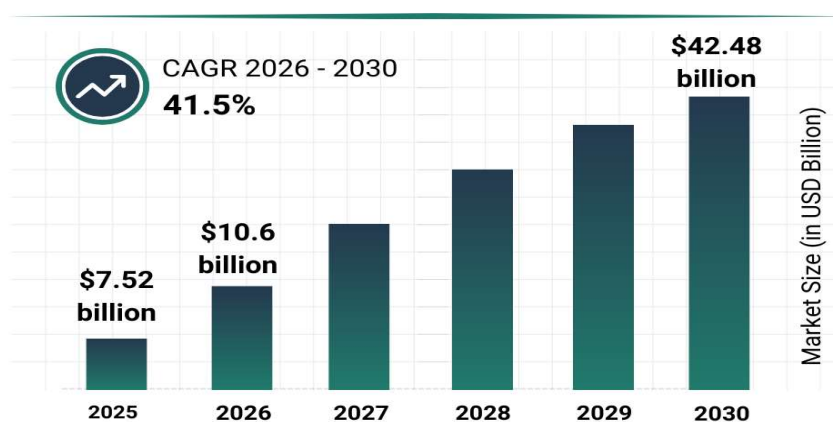
Equity considerations form an increasingly important dimension of the literature. Studies on the digital divide demonstrate that unequal access to digital infrastructure, AI literacy, and pedagogical support can shape who benefits from AI-enhanced learning environments (van Deursen & Helsper, 2022; OECD, 2023). In secondary education, these inequalities may be further amplified if LLM technologies are introduced without adequate teacher training and institutional support. Consequently, several scholars argue for a cautious, pedagogically mediated approach in which teachers remain central actors in guiding and contextualizing AI-supported learning (Holmes et al., 2019; Kasneci et al., 2023).

Overall, the reviewed literature indicates that while LLM technologies hold significant promise for enhancing geography education through personalized support, inquiry facilitation, and cognitive scaffolding, their effective use requires strong theoretical justification and methodological clarity. Existing research highlights the need for subject-oriented frameworks that integrate LLMs into geography teaching in ways that support disciplinary thinking, align with curriculum goals, and address ethical and equity-related concerns. This review therefore underscores the importance of developing a coherent methodological foundation for the pedagogical use of LLM technologies in general secondary geography education.

Methodology / Research Design. This study adopts a theoretical–analytical research design to examine the integration of large language model (LLM) technologies in general secondary geography education. The research focuses on identifying and systematizing theoretical foundations, methodological approaches, and pedagogical implications reported in contemporary scholarly literature.

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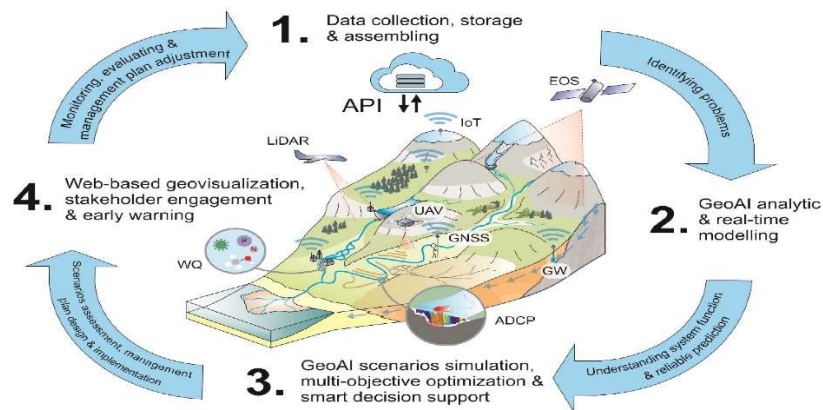
The literature corpus was compiled from ****peer-reviewed journal articles, international policy documents, and authoritative academic monographs**** in the fields of artificial intelligence in education and geography education. Sources were selected based on their relevance to secondary education, subject specificity, and conceptual contribution to AI-supported pedagogy.

Data analysis was conducted using thematic analysis, comparative synthesis, and pedagogical interpretation. The reviewed studies were categorized according to (a) underlying pedagogical theories, (b) subject-oriented applications in geography education, and (c) methodological and ethical considerations. This analytical structure enabled the identification of dominant research trends, recurring challenges, and gaps in the existing literature.

As a review-based study, this research does not involve empirical data collection. Its primary contribution lies in developing a conceptual and methodological framework that supports the pedagogically grounded use of LLM technologies in school geography. The findings provide a

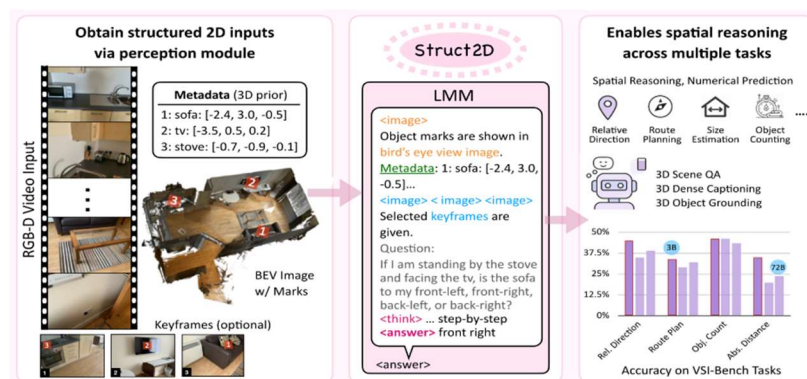
foundation for future empirical research and curriculum-oriented experimentation in AI-enhanced geography education.

Results and Discussion. The results of this theoretical–analytical review indicate that large language model (LLM) technologies are conceptually aligned with contemporary pedagogical paradigms that emphasize learner-centered, inquiry-oriented, and reflective learning. Across the reviewed literature, LLMs are consistently described as tools capable of supporting explanation, dialogue, and structured reasoning, which are central to effective learning in general secondary education. This alignment suggests that LLM technologies can be meaningfully integrated into school contexts when their use is guided by clear pedagogical objectives.



A key finding concerns the methodological relevance of LLMs for geography education. The analysis shows that geography, as a discipline grounded in spatial reasoning, textual interpretation, and systems thinking, benefits from LLM-supported activities such as comparative regional analysis, interpretation of geographic narratives, and explanation of complex human–environment interactions. These applications extend existing digital practices in geography education, particularly those based on GIS and interactive mapping, by strengthening students’ analytical and conceptual engagement with geographic content.

The reviewed studies further highlight the potential of LLM technologies to support differentiated instruction and formative assessment. By generating adaptive prompts, feedback, and alternative explanations, LLMs can assist teachers in addressing diverse learning needs within secondary classrooms. This function is particularly relevant in geography education, where students’ prior knowledge and spatial thinking abilities often vary considerably. However, the literature emphasizes that such benefits depend on teachers’ ability to design and mediate LLM-supported tasks in alignment with curriculum standards.



At the same time, the results reveal significant pedagogical and ethical challenges. Several authors caution that uncritical reliance on LLM-generated content may lead to superficial learning,

reduced student autonomy, or the reproduction of factual inaccuracies. Concerns related to academic integrity, data privacy, and transparency are especially pronounced in secondary education, where learners are still developing critical evaluation skills. These findings reinforce the view that LLM technologies should function as supportive tools rather than autonomous instructional agents.

Another important dimension emerging from the analysis relates to educational equity and teacher competence. The literature indicates that disparities in digital infrastructure, AI literacy, and professional training may influence the effectiveness of LLM integration in schools. Without adequate institutional support and teacher professional development, the use of LLM technologies risks amplifying existing inequalities between schools and learners. Consequently, scholars stress the importance of systematic teacher training and policy frameworks that promote equitable access to AI-supported educational resources.

Overall, the results and discussion underscore that the educational value of LLM technologies in geography education is not inherent to the technology itself, but is shaped by pedagogical design, disciplinary alignment, and ethical oversight. When embedded within theoretically grounded and methodologically sound frameworks, LLMs have the potential to enrich geography teaching by supporting inquiry, explanation, and reflective learning. At the same time, the findings highlight the need for continued research and cautious implementation to ensure that LLM technologies contribute to meaningful and equitable educational outcomes in general secondary education.

Conclusion. This review has demonstrated that large language model (LLM) technologies represent a promising yet complex innovation for general secondary education, particularly within the context of geography teaching. The synthesis of contemporary literature confirms that LLMs align with key pedagogical paradigms, including constructivist, cognitive, and inquiry-based learning approaches, by supporting explanation, dialogue, and structured reasoning. In geography education, these affordances are especially relevant due to the subject's emphasis on spatial interpretation, systems thinking, and analysis of socio-environmental processes.

At the same time, the findings emphasize that the educational value of LLM technologies is highly dependent on pedagogical mediation and disciplinary alignment. Effective integration requires teachers to actively guide LLM-supported learning activities, ensuring consistency with curriculum objectives, age-appropriate use, and ethical standards. Without such mediation, LLM technologies risk contributing to superficial learning, reduced critical engagement, or unequal educational outcomes. These considerations highlight the central role of teacher competence and institutional support in AI-enhanced geography education.

In conclusion, LLM technologies should be conceptualized as supportive pedagogical tools rather than autonomous instructional agents in general secondary education. Their successful use in geography classrooms depends on theoretically grounded methodological frameworks, professional development for teachers, and policies that promote ethical and equitable access. Future research should build on these conceptual insights through empirical studies that examine classroom implementation, learning outcomes, and long-term impacts of LLM-supported geography instruction.

Limitations and Future Research. Despite its contributions, this study has several limitations that should be acknowledged. First, the research is based on a theoretical–analytical review and does not include empirical classroom data. As a result, the conclusions rely on the synthesis of existing literature rather than direct observation of LLM-supported geography instruction in secondary school settings. While this approach is appropriate for conceptual clarification, it limits the ability to assess practical effectiveness and learning outcomes.

Second, the reviewed literature predominantly reflects research conducted in technologically advanced educational contexts. Consequently, the findings may not fully capture

the challenges faced by schools with limited digital infrastructure or insufficient teacher training. This limitation is particularly relevant for general secondary education, where disparities in access to AI technologies and digital competencies remain pronounced.

Future research should therefore focus on **empirical validation** of the proposed methodological directions through classroom-based experiments, mixed-methods studies, and longitudinal designs. Further studies are also needed to explore teachers' professional readiness, students' critical AI literacy, and ethical governance frameworks for LLM use in geography education. Such research would strengthen the evidence base for sustainable and equitable integration of LLM technologies in school geography curricula.

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ПОНЯТИЕ И СУЩНОСТЬ ПРЕДМЕТНОГО УМЕНИЯ В СИСТЕМЕ STEM-ОБРАЗОВАНИЯ

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Современные тенденции развития образования обусловлены необходимостью подготовки личности, способной к продуктивной деятельности в условиях быстро меняющегося технологического и информационного пространства. В этой связи особую актуальность приобретает STEM-образование (Science, Technology, Engineering, Mathematics), ориентированное на интеграцию научных знаний, инженерного мышления и практико-ориентированной деятельности обучающихся [1]. Ключевым результатом STEM-образования выступает не столько усвоение совокупности знаний, сколько формирование у обучающихся системы предметных умений, обеспечивающих применение знаний в реальных и учебно-практических ситуациях [2].

В условиях обновления содержания образования и перехода к деятельностной парадигме возникает необходимость теоретического осмысления понятия и сущности предметного умения в системе STEM-образования, определения его структуры, функций и педагогического потенциала [3].

В педагогической литературе категория «умение» тесно связана с деятельностью. Умение-это освоенный способ выполнения действий, основанный на осознанном применении знаний и опыта в изменяющихся условиях [4].

Психологический аспект трактует умение как компонент деятельности, формирующийся на основе знаний и навыков и предполагающий сознательный контроль выполнения действий [5]. В отличие от навыка, который характеризуется автоматизированностью, умение сохраняет осознанность и вариативность применения.

Таким образом, умение выступает промежуточным звеном между знанием и деятельностью, обеспечивая перенос теоретических положений в практическую плоскость.

Понятие «умение» имеет два значения:

1. Начальный уровень овладения простым действием, в этом случае умение переходит в навык;
2. Выполнение сложного действия с помощью навыков.

С одной стороны, для того чтобы человек научился писать, считать, читать и тому подобное, он должен знать, как это делать. Получая знания, у него вырабатывается умение. В ходе практической деятельности умения становятся все более совершенней и совершенней.

С другой стороны, умения можно приобрести путем упражнения. Упражнение-это многократное повторение определенных действий. Например, умение ходить и говорить – это упражнение подражание взрослым.

По итогу в результате длительных упражнений деятельность становится правильной, точной, быстрой и безошибочной, т.е. она становится автоматизированной в результате упражнений.

Концептуальные подходы к рассмотрению понятия «умение»:

- Деятельностный подход: умение-это знание в действии;
- Личностный подход: умение-это качество личности;
- Личностно-деятельностный подход: формирование умения происходит в деятельности и умение проявляет как способность к целенаправленной деятельности [6].

Чаще всего исследователи придерживаются личностно-деятельностного подхода, так как именно такой подход дает возможность включить умение в структуру учебных действий и рассматривать как компонент учебной деятельности, а также рассматривать как характеристику личности.

Предметное умение рассматривается как способность обучающегося выполнять учебно-познавательные и практические действия в рамках конкретной предметной области с опорой на систему предметных знаний, методов и способов деятельности. В отличие от универсальных (метапредметных) умений, предметные умения имеют четкую содержательную и функциональную привязку к конкретному учебному предмету (математика, естествознание, технология и др.).

Сущность предметного умения проявляется в следующих характеристиках:

- опора на предметное знание;
- направленность на решение учебных и практических задач;
- осознанность и вариативность применения;
- связь с содержанием и логикой конкретной науки.

В системе STEM-образования предметные умения приобретают интегративный характер, поскольку формируются во взаимосвязи нескольких предметных областей.

STEM-образование ориентировано на формирование у обучающихся способности использовать знания из области науки, технологии, инженерии и математики для решения комплексных задач. В этом контексте предметное умение трансформируется из узко предметного в функционально-интегрированное.

Предметные умения в STEM-системе включают:

- умение применять математические методы для анализа и моделирования;
- умение проводить наблюдения, эксперименты, измерения;
- умение проектировать, конструировать и тестировать модели;
- умение использовать цифровые и технологические инструменты.

Особенностью STEM-предметных умений является их практико-ориентированность и направленность на создание продукта (модель, проект, решение инженерной задачи).

Анализ психолого-педагогической литературы позволяет выделить следующую структуру предметного умения:

1. *Когнитивный компонент*-система предметных знаний, понятий, законов и теорий, необходимых для выполнения действий.
2. *Операционально-деятельностный компонент*-совокупность способов, методов и приемов выполнения предметных действий.
3. *Практико-применительный компонент*-способность использовать умение в учебных и реальных ситуациях, включая решение инженерных и исследовательских задач.
4. *Рефлексивный компонент*-умение анализировать процесс и результат собственной деятельности, корректировать способы действия.

Такая структура обеспечивает целостность формирования предметного умения и соответствует логике STEM-деятельности.

Предметные умения выполняют ряд важных функций:

- *познавательную*, обеспечивая осмысленное усвоение знаний;
- *практическую*, направленную на применение знаний;

- *интегративную*, объединяющую содержание разных предметов;
- *развивающую*, способствующую формированию инженерного мышления;
- *профессионально-ориентационную*, создающую предпосылки для выбора STEM-профессий.

Формирование предметных умений в системе STEM-образования способствует развитию познавательной активности, исследовательских способностей и творческого мышления обучающихся. Использование проектной, исследовательской и инженерно-конструкторской деятельности позволяет обеспечить прочную связь теории и практики.

Особенно значимым является формирование предметных умений на начальных и основных уровнях образования, где закладываются основы научного мышления и интерес к STEM-дисциплинам.

Предметное умение в системе STEM-образования представляет собой интегративное образование личности, обеспечивающее осознанное и вариативное применение предметных знаний в учебно-практической и инженерной деятельности. Его сущность заключается в единстве знаний, способов действий и практического опыта, а формирование выступает одним из ключевых условий эффективности STEM-образования.

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THE EFFECTIVENESS OF USING THE «CASE STUDY» METHOD IN TEACHING THE «RESPIRATION» UNIT OF THE SECONDARY SCHOOL BIOLOGY CURRICULUM

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Abstract. The article examines the pedagogical effectiveness of using the «Case Study» method in teaching the «Respiration» section of the secondary school biology course. The study analyzed the method's impact on increasing students' interest in the subject, developing critical thinking abilities, and forming skills to apply theoretical knowledge in practical situations. The article describes the features of using the «Case Study» method in biology lessons, examples of practical tasks, research results, and the teacher's role in organization. In conclusion, the "Case Study" method is presented as an effective pedagogical approach that allows increasing students' cognitive activity and improving the quality of education.

Keywords: biology, respiration, Case Study, active learning, critical thinking

ОРТА МЕКТЕПТЕ БИОЛОГИЯ КУРСЫНЫҢ «ТЫНЫС АЛУ» БӨЛІМІН ОҚЫТУДА «CASE STUDY»
ӘДІСІН ҚОЛДАНУДЫҢ ТИІМДІЛІГІ
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Аңдатпа. Мақалада орта мектепте биология курсының “Тыныс алу” бөлімін оқытуда “Case Study” әдісін қолданудың педагогикалық тиімділігі қарастырылады. Зерттеу барысында әдістің оқушылардың пәнге қызығушылығын арттыруға, сыни ойлау қабілетін дамытуға және теориялық білімді практикалық жағдайларда қолдану дағдыларын қалыптастыруға әсері талданды. Сонымен қатар “Case Study” әдісінің биология сабағында қолдану ерекшеліктері, практикалық тапсырма үлгілері, зерттеу нәтижелері және мұғалімнің ұйымдастырудағы рөлі көрсетілген. Қорытындылай келе, “Case Study” әдісі оқушылардың танымдық белсенділігін арттырып, білім сапасын жоғарлатуға мүмкіндік беретін тиімді педагогикалық тәсіл ретінде ұсынылады.

Кілттік сөздер: биология, тыныс алу, Case Study, белсенді оқыту, сыни ойлау

Қазіргі білім беру жүйесінің басты мақсаты - оқушылардың функционалдық сауаттылығы мен сыни ойлауын дамыту, яғни олардың алған білімін өмірде, нақты бір жағдайларда қолдана алу қабілетіне дағдылау. Бұл мақсатқа жету үшін оқыту әдістерін жаңартып, дәстүрлі әдістен бас тарту. Себебі дәстүрлі әдіс оқушыларды тек дайын ақпаратты қабылдаушы ретінде қалыптастырады. Ал заманауи білім беру жүйесі оқушыны білімді өз бетінше құрастырушы, белсенді тұлға ретінде тәрбиелеуге бағытталған.

Жалпы биология пәні оқушыларға табиғат құбылысын ғылыми тұрғыда қабылдап түсінуіне, тірі ағзалардағы үдерістерді бақылауына мүмкіндік береді. Мектепте биология курсына “Тыныс алу” бөлімі ерекше маңызды бөлімдердің бірі, себебі бұл бөлімде тірі

ағзалардың негізгі тіршілік етуінің физиологиялық құрылымы берілген. Дегенмен, тыныс алу механизмдері мен газ алмасу үдерістерінің күрделілігі бұл тақырыпты оқыту барысында белгілі бір қиындықтарды туындатуы мүмкін. Сондықтан теориялық білімді практикалық жағдаймен ұштастыратындай әдіс тәсілдерді қолданған тиімді.

XXI ғасырдың зерттеулерінде көрсетілгендей, оқушылар берілген білімді терең меңгеруі үшін оны нақты өмірлік мысалдармен байланыстырып түсіндіру қажет. Осы мақсатта педагогтар “Case Study” әдісін қолдану негізгі мәселенің шешімі деп санайды. Бұл әдіс нақты немесе өмірге жақын жағдайларды талдап, талқылау арқылы оқушыларды мәселені шешуге, өз пікірін ашық айтып, оны нақты дәлелдеуге және қорытынды жасауға үйретеді.

“Case Study” әдісі білім беру саласына сонау XX ғасырдың 20 жылдарынан бастап енгізіле бастады. Егер “Case Study” әдісін қазақ тіліне аударатын болсақ, нақты мәселеге, оқиғаға талдау жасау әдісі деп айтуға болады. Қазіргі кезде “Case Study” әдісінің екі түрі бар. Біреуі - гарвардтық (американдық) және еуропалық (манчестрлік) [4]. Бірінші әдіс тәсіл бойынша бір ғана дұрыс жауабы болса, екінші мәселені шешудің көп түрлі жолын немесе әдісін іздестіру арқылы шешімін табу әдісі.

“Case Study” әдісінің мәні - оқушылардың ойлау қабілетімен қатар, сыни талдау жасау қабілетін дамытып, өз ойын ашық білдіруге бағыттау[5]. Әдіс барысында оқушылар мәселені өз бетінше талдайды, шешімін іздейді және қорытынды шығарады [1]. Мұндай ойландырып, шешімін өзі табуды талап ететін тапсырмалар оқушылардың қызығушылығын арттырып қана қоймай, логикалық және зерттеушілік дағдыларын қалыптастырады. Сонымен қоса, әдіс оқушылардың коммуникативтік дағдыларымен де жұмыс істеуге мүмкіндік беріп үйретеді. Бұл әдістің басты ерекшелігі - оқушыны дайын ақпаратты қабылдаушы емес, мәселені шешуші тұлға ретінде қарастыруы. Педагогикалық тұрғыдан алғанда, “Case Study” әдісі:

- оқушылардың сыни және логикалық ойлауын дамытады;
- теориялық білімді практикалық жағдаймен байланыстырады;
- өз ойын дәлелдеп айту, пікірталас жүргізу дағдыларын қалыптастырады;
- топта жұмыс істеу мәдениетін дамытады;

Биология сабағында “Тыныс алу” бөлімін оқытуда “Case Study” әдісін қолдану оқушыларға биологиядағы қиын да күрделі тақырыптардың бәрін түсініп, теориялық білімді нақты тіршілік жағдаймен байланыстыруға мүмкіндік береді. Мысал келтіретін болсақ, физикалық жүктеме кезінде тыныстың жиілеуі, таулы аймақтарда оттегінің азаюы немесе жабық бөлмеде ұзақ уақыт отырудың адам ағзасына әсері сияқты жағдайларды талдау арқылы оқушылар тыныс алу жүйесінің қызметін терең түсінеді [3]. Мұндай тапсырмалар оқушыларды денсаулыққа, қоршаған ортаға жауапкершілікпен, сезіммен қарауына дағдылайды.

Case Study әдісін қолдану барысында келесі бағыттар тиімді болып табылады:

- тыныс алу жүйесінің ауруларына байланысты жағдаяттарды талдау;
- физикалық жүктеме кезінде тыныс алудың өзгеруін зерттеу;
- экологиялық факторлардың тыныс алу процесіне әсерін қарастыру;

Мысалы, оқушыларға “Тауға көтерілген адамда тыныс алудың жиілеу себебі неде?” немесе “Темекі шегудің тыныс алу жүйесіне әсері” сияқты жағдаяттық тапсырмалар ұсынылады. Бұл тапсырмалар арқылы оқушылар тыныс алу бөлімін тіршілікпен байланыстырып физиологиялық негізін терең түсінеді. Оқушылар “Case Study” әдісі арқылы тыныс алу мүшелерінің құрылысы мен қызметін, өкпеде жүретін газ алмасу үдерістерін, жасушалық тыныс алу маңызын меңгереді. Олар теориялық білімді практикамен ұштастыра отырып, күнделікті тіршілікте пайдалана алады.

Практикалық зерттеу барысында “Case Study” әдісінің тиімділігін анықтау мақсатында орта мектептің 8-сынып оқушылары арасында тәжірибелік жұмыс жүргізілді. Зерттеу

барысында 8-сынып оқушылары екі топқа бөлінді: 1-топ бақылау тобы (дәстүрлі әдістер), 2-топ тәжірибелік топ (“Case Study” әдісі қолданылады). Яғни 1-топ оқушыларына тек дәстүрлі түрде сабақ жүргізілсе, 2-топ оқушыларына арнайы сол тақырыптарға байланысты “Case Study” тапсырмалары қолданылды. Зерттеу бірнеше аптаға созылды. Оқушыларға берілген “Case Study” тапсырмаларының мынадай түрлері болды:

Кейс-1. “Тауға шыққан оқушы”

Жағдаят сипаттамасы: Айдос тауға саяхатқа шықты. Тауға көтерілген сайын оның тыныс алуы жиілеп, жүрек соғысы жиілеп, жүрек соғысы күшейе түсті. Ол өзін әлсіз сезіне бастады.

Тапсырмалар:

1. Айдостың тыныс алуының жиілеу себебін түсіндіріңіз.
2. Бұл жағдайда оттегінің ағзадағы рөлі қандай?
3. Тыныс алу мен қан айналым жүйесінің өзара байланысын анықтаңыз.

Күтілетін нәтиже: оқушылар оттегінің азаюы, газ алмасу және тыныс алудың реттелуі туралы білімдерін қолданады.

Кейс-2. “Спорт сабағынан кейін”

Жағдаят сипаттамасы: дене шынықтыру сабағында оқушылар 1000 метр қашықтыққа жүгірді. Жүгірістен кейін олардың тынысы жиілеп, тершеңдік байқалды.

Тапсырмалар:

1. Физикалық жүктеме кезінде тыныс алудың неге жиілейтінін түсіндіріңіз.
2. Жасушалық тыныс алу процесінің бұл жағдайдағы маңызын атаңыз.
3. Қалпына келу кезінде тыныс алу қалай өзгереді?

Күтілетін нәтиже: оқушылар тыныс алу мен энергия түзілу арасындағы байланысты түсінеді.

Зерттеу соңында екі топтың да оқушыларынан сабаққа қатысты сауалнама алынды. 1-топ оқушылары яғни, сабағы дәстүрлі өткен оқушылардың сауалнама нәтижесі 2-топтан яғни, сабағы “Case Study” әдісімен жүргізілген оқушыларға қарағанда төмен нәтиже көрсетілді.

2-топ. Нәтижесі



1-топ. Нәтижесі



Зерттеу нәтижелері көрсеткендей жағдаяттық тапсырмалар қолданылған сабақтарда оқушылардың пәнге деген қызығушылығы артып, олардың сабаққа белсенді қатысуы байқалады. Оқушылар өз пікірін еркін білдіріп, топтық жұмыс барысында бір-бірімен еркін пікір алмасып, бір-бірінің ойларын тыңдап толықтыруды үйренді.

Ал дәстүрлі әдістер қолданылған оқушылардың белсенділігі төменірек болады. Сонымен қатар, “Case Study” әдісі оқушылардың коммуникативті дағдыларын дамытуға да оң әсерін тигізеді. Топтық талқылау барысында оқушылар өз ойын нақты жеткізуге, қарсы пікірді таңдауға және өз көзқарасын дәлелдеуге үйренеді. Бұл дағдылар қазіргі қоғамда тұлғаның табысты қалыптасуы үшін маңызды болып табылады [4].

“Case Study” әдісін тиімді қолдану оны оқушылар пайдасына асыру, мұғалімнің кәсіби даярлығына да байланысты. Мұғалім жағдаяттық тапсырмаларды оқушылардың жас ерекшелігі мен білім деңгейіне сай құрастыруы тиіс. Сонымен қатар, оқушылардың еркін ойлауына жағдай жасап, олардың пікірін бағалап, қолдау көрсетуі керек. Мұғалім бұл жағдайда бағыттаушы және кеңесші рөлін атқарады.

Қорытындылай келе, орта мектеп биология құрысының “Тыныс алу” бөлімін оқытуда “Case Study” әдісін қолдану оқушылардың танымдық белсенділігін арттырады, пәнге қызығушылығын күшейтеді және теориялық білімді практикамен ұштастыруға мүмкіндік береді. Жалпы бұл әдіс оқушылардың сыни ойлау, талдау және коммуникативтік дағдыларын дамытып, өмірлік жағдайларда алған білімін қолдануға үйретеді. Сондықтан “Case Study” әдісін биология сабақтарында жүйелі түрде қолдану қазіргі білім беру талаптарына толық сәйкес келеді.

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USING ICT IN STUDYING THE SECTIONS “REPRODUCTION” AND “GROWTH AND DEVELOPMENT” IN THE COURSE OF BIOLOGY OF SECONDARY SCHOOL

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Abstract. This article examines effective ways of using information and communication technologies (ICT) in teaching the sections “Reproduction” and “Growth and Development” in secondary school biology. The role of ICT tools in the educational process is analyzed, including their importance in enhancing students’ cognitive activity and presenting biological processes in a clear and visual way. In addition, the methodological possibilities of organizing biology lessons through digital resources, multimedia materials, interactive platforms, and computer modeling are explored. The pedagogical effectiveness of applying ICT technologies is highlighted, and practical recommendations for biology teachers are provided.

Keywords: biology, reproduction, growth and development, ICT, digital technologies, secondary school

ОРТА МЕКТЕП БИОЛОГИЯСЫНЫҢ «КӨБЕЮ», «ӨСУ ЖӘНЕ ДАМУ» БӨЛІМДЕРІН ОҚЫТУДА АКТ ТЕХНОЛОГИЯСЫН ҚОЛДАНУ

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Аңдатпа. Бұл мақалада орта мектеп биология пәнінің «Көбею» және «Өсу және даму» бөлімдерін оқыту барысында ақпараттық-коммуникациялық технологияларды (АКТ) тиімді қолдану жолдары қарастырылады. АКТ құралдарының оқу үдерісіндегі рөлі, олардың оқушылардың танымдық белсенділігін арттырудағы, биологиялық үдерістерді көрнекі әрі түсінікті жеткізудегі маңызы жан-жақты талданады. Сонымен қатар цифрлық ресурстарды, мультимедиялық материалдарды, интерактивті платформалар мен компьютерлік модельдеулерді пайдалану арқылы биология сабағын жаңаша ұйымдастырудың әдістемелік мүмкіндіктері көрсетіледі. Мақалада АКТ технологияларын қолданудың педагогикалық тиімділігі айқындалып, биология пәні мұғалімдеріне арналған практикалық ұсыныстар беріледі.

Кілттік сөздер: биология, көбею, өсу және даму, АКТ, цифрлық технологиялар, орта мектеп

Кіріспе. Цифрландыру үдерісінің қарқынды дамуы білім беру жүйесіне де жаңа талаптар қойып отыр. Қазіргі мектеп түлегі тек теориялық білімді меңгеріп қана қоймай, оны талдап, салыстырып, нақты жағдайларда қолдана алуы тиіс. Осы тұрғыдан алғанда, функционалдық сауаттылық пен сыни ойлауды дамыту – биология пәнін оқытудың маңызды міндеттерінің

бірі болып табылады. Бұл міндетті жүзеге асыру үшін оқыту үдерісіне заманауи ақпараттық-коммуникациялық технологияларды енгізу қажеттілігі туындайды.

Ақпараттық-коммуникациялық технологиялар (АКТ) XX ғасырдың екінші жартысында компьютерлік техниканың дамуымен бірге қалыптаса бастады. Алғашында АКТ есептеу және ақпаратты сақтау құралы ретінде қолданылса, кейіннен білім беру саласына біртіндеп енгізіліп, оқыту мазмұны мен әдістерін жаңартудың маңызды тетігіне айналды. XXI ғасырда цифрландыру үдерісінің қарқынды дамуына байланысты АКТ технологиялары білім беру жүйесінің ажырамас бөлігіне айналып, оқушылардың функционалдық сауаттылығы мен сыни ойлауын қалыптастырудың тиімді құралы ретінде қарастырылады.

Биология пәні – тірі ағзаларда жүретін күрделі үдерістерді зерттейтін ғылым болғандықтан, оны оқытуда көрнекілік пен тәжірибелік бағыт ерекше маңызды. Орта мектеп биология курсына «Көбею» және «Өсу және даму» бөлімдері жасушалық бөліну, ұрықтың дамуы, ағзаның жеке қалыптасу кезеңдері сияқты динамикалық және көзге көрінбейтін үдерістерді қамтиды. Бұл тақырыптарды дәстүрлі тәсілдер арқылы түсіндіру оқушылардың толық әрі терең түсінуіне әрдайым мүмкіндік бере бермейді.

Осыған байланысты биология сабақтарында АКТ технологияларын, соның ішінде компьютерлік модельдеу мен интерактивті 3D-анимацияларды қолдану ерекше өзектілікке ие. Бұл технологиялар биологиялық үдерістерді қозғалыс барысында, уақыт бойынша өзгеру динамикасымен көрсетуге мүмкіндік береді. Нәтижесінде оқушылар күрделі биологиялық құбылыстарды көзбен көріп, олардың құрылымы мен қызметін салыстырып, себеп-салдарлық байланысын саналы түрде түсінеді.

Осылайша, «Көбею» және «Өсу және даму» бөлімдерін оқытуда АКТ технологияларын пайдалану оқушылардың танымдық белсенділігін арттырып, биология пәнін меңгерудің сапасын жаңа деңгейге көтереді. Компьютерлік модельдеу – нақты биологиялық нысандар мен үдерістерді цифрлық ортада қайта құрастыруға негізделген АКТ технологиясы. Бұл әдіс оқушыларға зерттелетін үдерісті әр қырынан бақылауға, оның кезеңдерін бөлек-бөлек талдауға мүмкіндік береді.

«Көбею» бөлімін оқытуда компьютерлік модельдеу:

- митоз және мейоз фазаларын қозғалыста көрсетуге;
- ұрықтану мен эмбриондық дамудың кезеңдерін бірізділікпен талдауға;
- жынысты және жыныссыз көбею түрлерін салыстыруға жағдай жасайды.

Ал «Өсу және даму» бөлімінде бұл технология:

- ағзаның жеке даму кезеңдерін визуалды түрде көрсетуге;
- ішкі және сыртқы факторлардың даму қарқынына әсерін модельдеуге;
- өсу мен дамудың өзара байланысын түсіндіруге мүмкіндік береді.

Осылайша, компьютерлік модельдеу биология сабағында оқушылардың дербес ойлауын дамытып, оқу материалының мазмұнын терең түсінуге ықпал етеді.

Компьютерлік модельдеудің тиімділігін анықтау мақсатында орта мектептің 8-сынып оқушылары арасында педагогикалық зерттеу жүргізілді. Зерттеуге жалпы 8-сыныптың екі параллель сыныбы қатысты.

Зерттеу келесі кезеңдер бойынша ұйымдастырылды:

- Бақылау тобы – «Көбею» және «Өсу және даму» бөлімдері дәстүрлі әдістер (оқулық, мұғалімнің түсіндіруі, статикалық суреттер) арқылы оқытылды;
- Тәжірибелік топ – сабақ барысында интерактивті 3D-анимациялар мен компьютерлік модельдер қолданылды.

Әр тақырыптан кейін оқушыларға білімді бекітуге арналған тапсырмалар, бақылау сұрақтары және шағын тесттер берілді. Сонымен қатар сабақ соңында оқушылардың пәнге қызығушылығын анықтау мақсатында сауалнама жүргізілді.

Тапсырма 1. «Митоз фазаларын модельдеу»

Оқушыларға жасушаның бөліну процесі көрсетілген 3D-анимация ұсынылды.

1. Әр фазада жүретін негізгі өзгерістерді анықтаңыз.
2. Қай фазада хромосомалар айқын көрінеді?
3. Модель негізінде митоздың биологиялық маңызын түсіндіріңіз.

Тапсырма 2. «Ағзаның даму кезеңдері»

Компьютерлік модель арқылы ағзаның өсу кезеңдері көрсетілді:

1. Даму кезеңдерін ретімен орналастырыңыз.
2. Қай кезеңде өсу қарқыны жоғары болады?
3. Сыртқы орта факторлары өзгерсе, модельде қандай өзгеріс байқалады?

Күтілетін нәтиже: оқушылардың биологиялық үдерістерді (жасушалық бөліну, ұрықтың дамуы, ағзаның өсу кезеңдері) түсіну деңгейінің артуы.

Зерттеу нәтижелері көрсеткендей, компьютерлік модельдеу қолданылған тәжірибелік топта оқушылардың оқу жетістігі мен сабаққа белсенділігі айтарлықтай жоғары болды.

Тәжірибелік топ оқушылары:

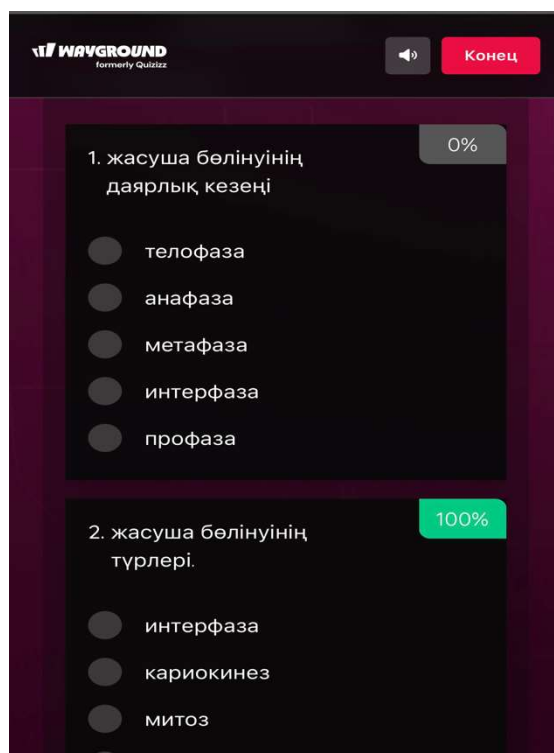
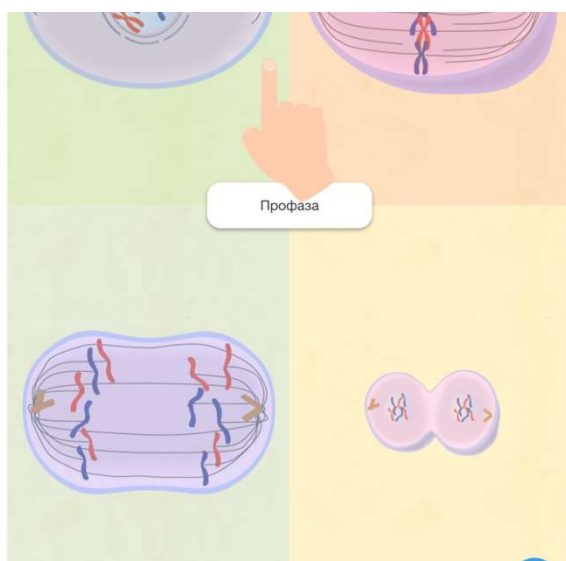
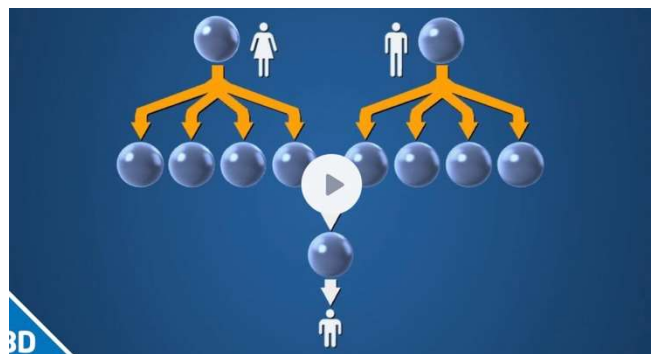
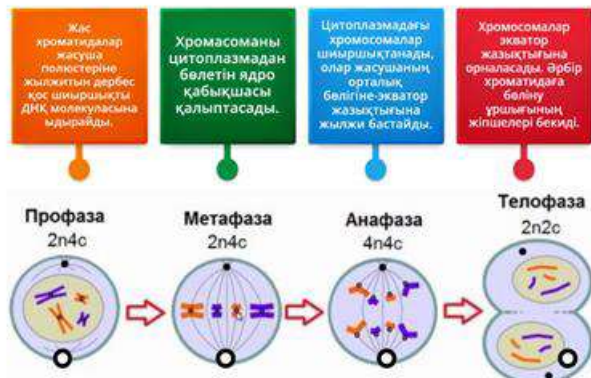
- биологиялық үдерістерді түсіндіруде нақты терминдерді жиі қолданды;
- тапсырмаларды орындау барысында логикалық байланыстарды дұрыс құрды;
- өз ойларын дәлелдеп айтуға бейімделді.

Ал бақылау тобында оқушылардың көпшілігі ақпаратты жаттап айтуға бейім болып, үдерістер арасындағы байланысты түсіндіруде қиналды. Сауалнама нәтижелері де тәжірибелік топ оқушыларының биология пәніне қызығушылығы артқанын көрсетті.

Сабақ барысында қолданылған тапсырмалар:

1.Wordwall платформасы.

2.Mozaweb.co m



3.LearningApps.org платформасы.

4.Wayground.com

1-Бақылау тобы.

2-Тәжірибелік тобы.



Нәтижелер көрсеткендей, тәжірибелік топ оқушыларының орташа ұпайы 87% болса, бақылау тобының орташа ұпайы 72% болды, бұл компьютерлік модельдеу қолданылған топта білім деңгейі айтарлықтай жоғары екенін дәлелдейді. Тәжірибелік топ оқушылары митоз, мейоз, ұрық дамуы мен ағзаның өсу кезеңдерін нақты және дұрыс сипаттай білді, ал бақылау тобы тек теориялық түсінікпен шектеліп, фазалар арасындағы байланыстарды дұрыс көрсете алмады. Сабаққа қатысу белсенділігі тәжірибелік топта 95% деңгейінде байқалды, топтық талқылаулар мен сұрақтарға жауап беру белсенділігі жоғары болды, ал бақылау тобының белсенділігі 65–70% шамасында қалды. Сонымен қатар тәжірибелік топ оқушылары компьютерлік модель арқылы әрбір үдерісті өз бетімен талдап, логикалық қорытынды жасай алды, ал бақылау тобы көбіне дайын жауапқа сүйеніп, проблемаларды талдау деңгейі төмен болды. Практикалық дағдылар бойынша тәжірибелік топ интерактивті тапсырмаларды орындау барысында әр фазаның физиологиялық және биологиялық мәнін түсіндірді, ал бақылау тобы тек мәтіндік сипаттамаға сүйеніп, практикалық талдау жасай алмады.

Зерттеу көрсеткендей, компьютерлік модельдеу қолданылған сабақтар оқушылардың күрделі биологиялық үдерістерді визуалды түсінуіне, теория мен практиканы байланыстыру қабілетіне, топтық және жеке жұмысқа белсенді қатысуына, сыни ойлау және талдау дағдыларын дамытуына оң әсерін тигізді. Сонымен қатар, компьютерлік модельдеу оқушылардың пәнге қызығушылығын арттырып, сабақ барысында өзіндік ізденіс пен тәжірибелік жұмысқа ынтасын күшейтті. Бұл АКТ технологиясы арқылы оқушылар теориялық білімді нақты өмірлік немесе практикалық мысалдармен байланыстырған кезде ақпаратты терең меңгеру мүмкіндігін айтарлықтай арттырады.

Қорытындылай келе, орта мектеп биологиясының «Көбею» және «Өсу және даму» бөлімдерін оқытуда компьютерлік модельдеу мен интерактивті 3D-анимацияларды қолдану білім сапасын арттырудың тиімді құралы екені анықталды. Бұл АКТ технологиясы оқушылардың күрделі биологиялық үдерістерді терең түсінуіне, теориялық білімді практикалық тұрғыда қолдануына мүмкіндік береді. Компьютерлік модельдеу оқушыларды дайын ақпаратты қабылдаушы емес, биологиялық үдерістерді зерттеуші тұлға ретінде қалыптастырады. Сондықтан бұл технологияны биология сабақтарында жүйелі түрде қолдану қазіргі білім беру талаптарына толық сәйкес келеді және оқу үдерісінің тиімділігін арттырады.

Research Gaps in Integrating the Sustainable Development Goals (SDGs) into Geography Education in Kazakhstan: Adapting the Whole-School Approach and Developing an SDG School Mapping Model

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Abstract

The integration of the Sustainable Development Goals (SDGs) into school education has become a strategic priority within global educational reform. In Kazakhstan, sustainability-related content is present in the geography curriculum, including themes on global challenges, environmental protection, and spatial thinking, as well as GIS and remote sensing components at the Grade 9 level. However, SDG integration remains largely implicit and fragmented, lacking a systematic mechanism aligned with UNESCO's Whole-School Approach. This study aims to design, pilot, and evaluate a scalable SDG School Mapping Model that connects curriculum content, GIS-based spatial analysis, school operations, governance processes, and competency-based assessment within a unified framework.

Using a mixed-methods research design, the study combines curriculum content analysis, teacher surveys and interviews, institutional readiness diagnostics, and a quasi-experimental pilot implementation in selected secondary schools. The model integrates SDG curriculum mapping (topic–SDG–indicator–task–assessment), a GIS-based school sustainability dashboard, and a governance monitoring cycle aligned with the “audit–plan–monitor” logic of green school standards.

Preliminary findings suggest that linking GIS with school-level sustainability indicators enhances students' spatial thinking and sustainability competencies while strengthening institutional coordination and evidence-based decision-making. The proposed model contributes to implementation research by bridging institutional whole-school standards with the spatial-data methodology of geography. It offers a context-sensitive, scalable framework for embedding SDG integration into Kazakhstan's secondary education system and supports the transformation of sustainability education from fragmented practice into a measurable and institutionally coordinated system.

Keywords: SDGs, Whole-School Approach, geography education, GIS, school mapping, sustainability competencies.

A bibliometric subject-area analysis of publications related to the integration of the Sustainable Development Goals (SDGs) into education reveals a strong interdisciplinary orientation. The majority of studies are concentrated in Education and Educational Research (36), Environmental Studies (35), Environmental Sciences (35), and Green and Sustainable Science and

Technology (35). These findings confirm that SDG-related research is predominantly framed within educational reform and environmental sustainability discourse.



Figure 1. Subject-area distribution of SDG integration research based on Web of Science online database analysis.

Additional contributions appear in Development Studies (7), Geography (6), and Interdisciplinary Social Sciences (5). However, despite the presence of geographical perspectives, relatively limited research explicitly addresses the systematic integration of SDGs into geography education at the school level, particularly through institutional or whole-school implementation models.

This distribution highlights several critical research gaps. First, there is a lack of structured models linking the Whole-School Approach with subject-specific implementation in geography education. Second, empirical frameworks connecting SDG monitoring with spatial (GIS-based) educational mapping remain underdeveloped. Third, context-specific institutional models for SDG integration in countries such as Kazakhstan are largely absent from the literature.

Therefore, this study seeks to address these gaps by developing and implementing an SDG School Mapping Model, adapting UNESCO's Whole-School Approach to the geography education system in Kazakhstan and providing a structured institutional and spatial framework for sustainable development integration.

The integration of the Sustainable Development Goals (SDGs) into education systems goes far beyond merely "adding a topic" to the curriculum on the international agenda. It represents a transformative educational task in which curriculum content, pedagogy, assessment, school culture, and governance decisions are interconnected. UNESCO's ESD for 2030 Roadmap emphasizes that the implementation of Education for Sustainable Development (ESD) requires a systemic approach, highlighting priority action areas such as policy alignment, learning environments, teacher capacity-building, youth engagement, and local-level action.[1]

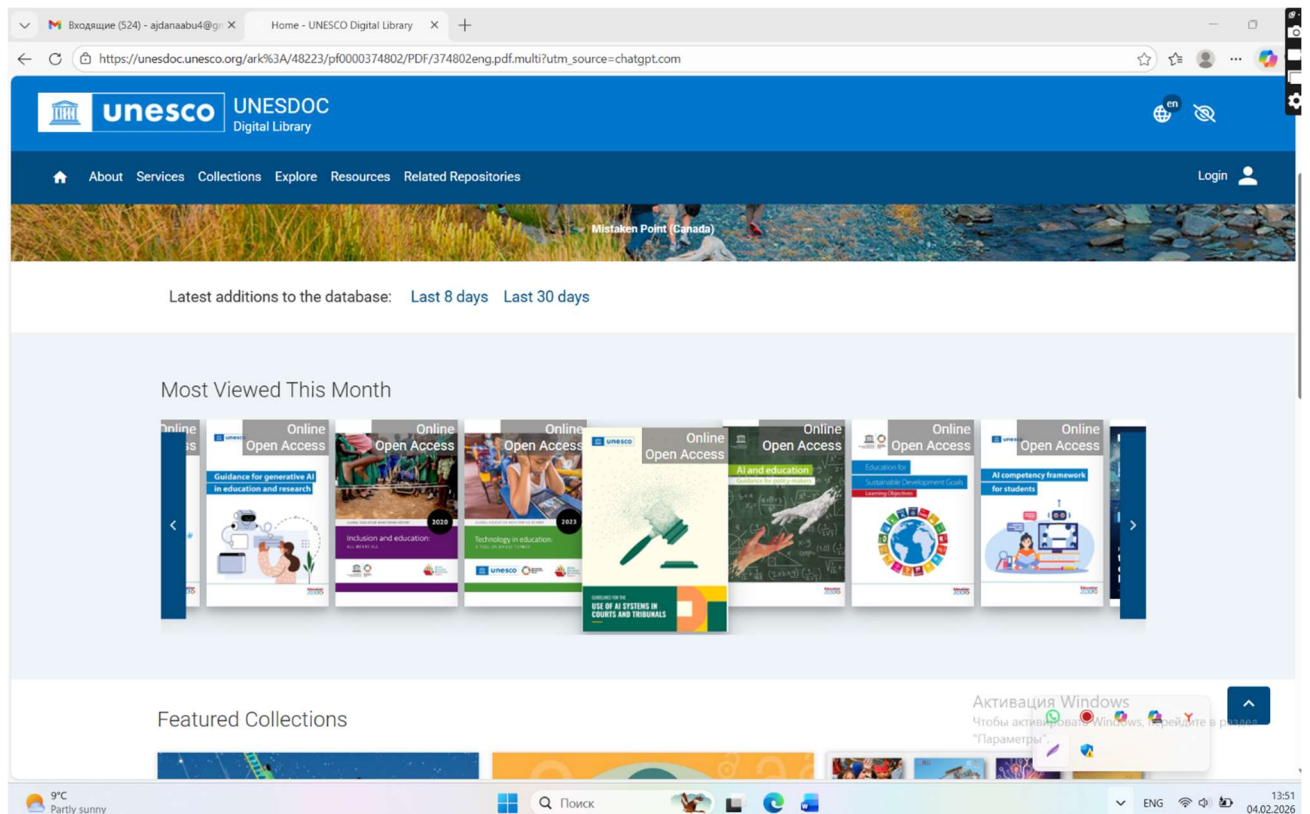


Figure 2. UNESCO Digital Library (UNESDOC) official platform interface used for accessing policy and SDG-related education documents.

As a practical “working formula” of this systemic logic, UNESCO has in recent years strengthened the Whole-School / Whole-Institution Approach principle. Within this framework, the concept of a “green school” is understood as a comprehensive set of simultaneous transformations carried out across teaching and learning processes, school governance, facilities and operations, as well as community partnerships.[2]

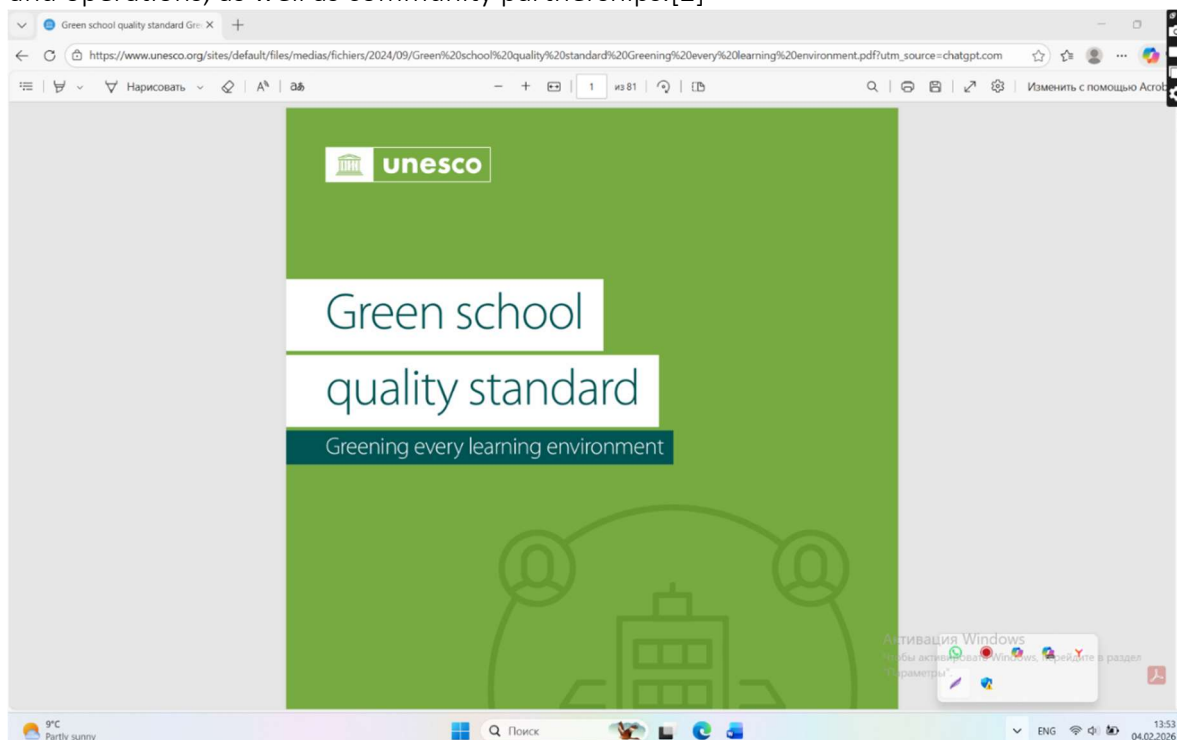


Figure 3. Cover page of UNESCO’s “Green School Quality Standard: Greening Every Learning Environment” (2024), used as a policy framework for institutional SDG integration.

Geography is one of the natural “anchor subjects” for integrating the Sustainable Development Goals (SDGs). This is primarily due to the very nature of geography as a discipline that explains spatial-temporal relationships, the “human–nature–society” system, and the interdependencies between local, regional, and global levels. The introduction to Kazakhstan’s model curriculum also emphasizes that geography studies spatial and temporal relationships between natural and anthropogenic objects, and identifies the development of spatial thinking and cartographic skills as one of its core objectives.[3]

In this context, the concept of a “research gap” is defined through three key questions:

- (1) What is the level of explicit and implicit integration of the SDGs in school geography education in Kazakhstan?
- (2) Why does this integration remain fragmented and fail to evolve into a school-level, systematically managed framework?
- (3) Can GIS and school mapping function as evidence-based integrators capable of overcoming this fragmentation?

Key Evidence in International Literature and Normative Frameworks

UNESCO’s Education for Sustainable Development Goals: Learning Objectives guidance emphasizes that progress toward the SDGs is achieved through education and provides specific learning objectives for each SDG across cognitive, socio-emotional, and behavioral domains. It also proposes thematic areas and learning activities aligned with these objectives. The document highlights that SDG-oriented education can be planned and implemented at multiple levels — from course design to national education strategies.[4]

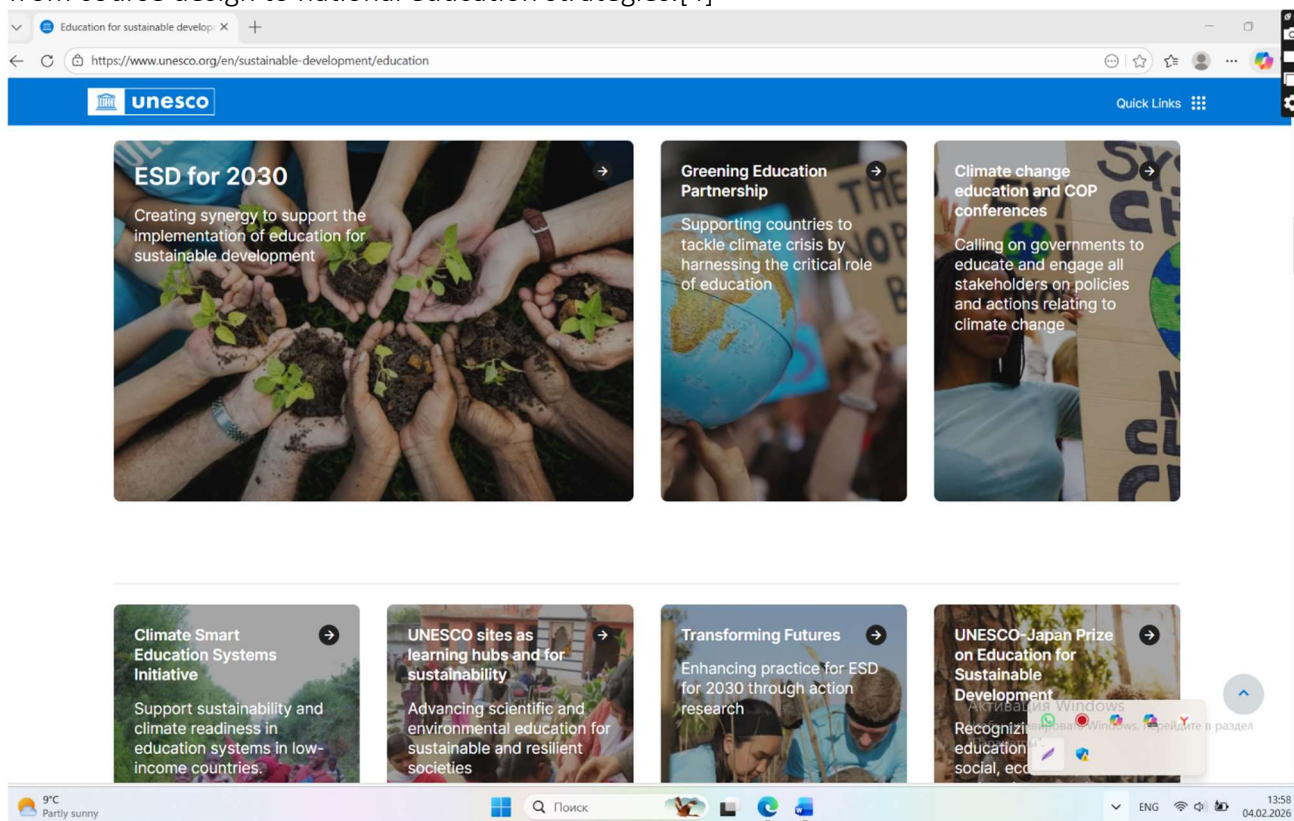


Figure 4. UNESCO Education for Sustainable Development (ESD for 2030) official webpage presenting global policy frameworks for SDG integration in education systems.

One of the most influential empirical models of the whole-school approach in education research is the Swedish framework used to measure the implementation of ESD in schools. In a study published in *International Research in Geographical and Environmental Education*, the ESD whole-school approach is operationalized through four dimensions:

- (a) a holistic vision,
- (b) school routines and structures,
- (c) professional knowledge creation, and
- (d) practical pedagogical work.

A key finding of the study is that teachers in schools actively implementing ESD tend to rate organizational quality and coherence highly. However, there is significant variability between schools, indicating that the institutional environment functions as a crucial “intervening variable” influencing ESD outcomes. [5]



Figure 5. Article page of “Whole school approaches to education for sustainable development” published in *Environmental Education Research* (2019), providing a theoretical model for institutional ESD implementation.

Recent review studies indicate that although ESD/SDG themes remain highly relevant in geography education, the evidence base at the school level is still limited. For example, a bibliometric analysis of ESD implementation in school geography between 2015 and 2024 (based on a relatively small sample of articles selected from major databases) concludes that while geography continues to be recognized as a key subject for ESD, further research is needed to improve curriculum content and teaching practices. [6]

The “curricular” direction of integrating SDGs into geography programs is also gaining momentum. For instance, research examining the integration of SDGs into the Chinese geography curriculum highlights the role of geography education in addressing global challenges and emphasizes the importance of both intra-disciplinary and interdisciplinary approaches. [7] At the empirical level (even though mainly in higher education contexts), studies show that linking geographical fieldwork with concrete SDG-related problems enables student learning experiences to become more action-oriented and practice-driven.[8]

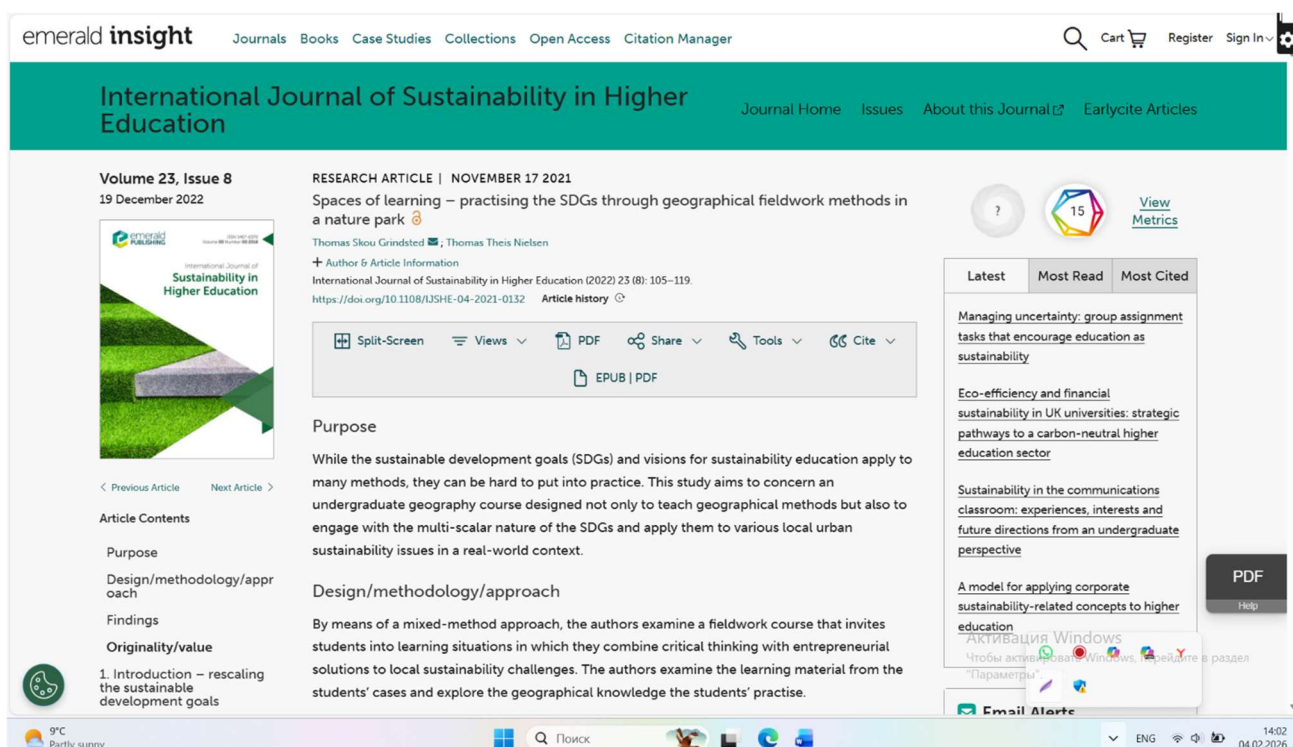


Figure 6. Article page of “Spaces of learning – practising the SDGs through geographical fieldwork methods” published in *International Journal of Sustainability in Higher Education* (2022), illustrating practical SDG integration in geography education.

International standards in geography education also explicitly link ESD with geography. The 2016 International Charter on Geographical Education, published by the International Geographical Union Commission on Geographical Education, affirms that geography education helps learners understand complex processes in society and nature, and emphasizes the importance of digital tools such as GIS for developing geographical literacy.[9] The 2007 Lucerne Declaration outlines specific criteria for integrating sustainable development principles into the geography curriculum and explicitly highlights the role of ICT — including GIS and GPS — in geography education.[10] This international body of evidence leads to a dual conclusion for Kazakhstan.

First, SDG integration is not merely a matter of “adding topics” to subject content; it depends fundamentally on the school as an organization — including governance structures and professional development systems.

Second, geography as a discipline offers the capacity to transform this change into an evidence-based and measurable system through the use of spatial data and GIS technologies.[11]

The Representation of the SDGs in Kazakhstan’s Education Policy and Geography Curriculum The Concept for the Development of Education in Kazakhstan for 2023–2029 has been officially approved by a Resolution of the Government of Kazakhstan, and its text has been published as a state policy document.[12] The Concept explicitly states that the renewal of educational content and methodology should be based on learner-centered and competence-based approaches. It further emphasizes that the development of functional literacy, as well as the formation of subject-specific, meta-subject, and key competencies, constitutes the core of educational content improvement.[13] At the same time, the document highlights an institutional issue related to the improvement of assessment practices: it identifies as a “problem” the lack of systematic, planned work in the regions aimed at implementing recommendations derived from international and national monitoring studies. This represents an important policy-level diagnosis, pointing to weaknesses in institutional coordination at the school level.[13]

In the publicly available textual version of the Model Curriculum for Geography (Grades 7–9), the subject objectives explicitly include enabling students to understand the potential for addressing contemporary human and global challenges, explaining the foundations of environmental protection and sustainable use of natural resources, and developing spatial thinking and cartographic skills.[3] These provisions demonstrate an implicit alignment of geography with the SDGs/ESD at the subject level: geography provides a ready-made disciplinary framework for explaining and analyzing issues related to sustainable development.[14]

However, explicit framing of SDG integration remains limited within the curriculum. In the Grade 9 core content, the concept of “sustainable development” appears as a distinct topic within the economic geography section. In this context, it is presented alongside components such as “models and types of natural resource use” and “problems associated with natural resource utilization.”[15] At the same time, the inclusion in the Grade 9 curriculum of content elements such as “methods of remote sensing of the Earth” and “applications of geographic information system (GIS) technologies” indicates that there is methodological potential within geography to conduct SDG-oriented spatial analysis. [16]

However, within the structure of the textual curriculum itself, there is no visible mechanism for systematically aligning the SDGs according to a “goal–indicator” logic (SDG-by-SDG tagging). In international literature, SDG integration is most often operationalized precisely through such alignment processes, linking specific goals and indicators with learning outcomes and assessment tools.[17] This leads to an important conclusion: in Kazakhstan’s school geography, sustainable development exists as a general concept, yet systematic “mapping” to specific SDGs and coordination at the level of the school as an organization have not yet been institutionalized.

The diagram below illustrates the indicative level of explicit integration within the curriculum (data based on the occurrence of specific concepts in the publicly available text of the Grade 7–9 model geography curriculum).[18]

Diagram: Visibility of Explicit SDG-Related Markers in Grades 7–9 Geography Curriculum (Present/Absent)

Marker	Grade 7	Grade 8	Grade 9
“Sustainable Development” concept (explicit)	Absent	Absent	Present [19]
GIS / Remote Sensing content (explicit)	Absent	Absent / Limited	Present [16]
Direct alignment with SDG indicators (explicit)	Not visible	Not visible	Not visible [20]

Note: The term “Not visible” in the last row reflects an analytical conclusion based on the publicly available version of the model curriculum text, indicating that no direct SDG goal/indicator-level tagging is present in that version. This statement should not be interpreted as an absolute claim covering all official annexes or every revision of the full curriculum documentation.[21]

GIS and School Mapping: Pedagogical Rationale and Implementation Constraints

The use of GIS and spatial data is particularly important for developing sustainability competencies, as the SDGs often require an understanding of spatial patterns such as inequality, resource distribution, risk zones, and infrastructure accessibility.

UNESCO’s “green school” standards likewise emphasize that a school’s progress toward sustainability should be measurable and managed at the school level, reinforcing the importance of evidence-based and spatially grounded approaches.[22]

The evidence base regarding the effectiveness of GIS in education continues to grow. A systematic review covering 257 studies published between 2010 and 2024 concludes that when GIS is applied within an appropriate pedagogical framework, it supports students’ geographical knowledge, spatial thinking, inquiry skills, and problem-solving abilities. However, the review also indicates

that the depth of GIS integration remains uneven, depending largely on teacher preparation, technical support, and its positioning within the curriculum.[23]

One of the studies illustrating concrete mechanisms for linking GIS with sustainability themes examines teacher agency in GIS integration. It argues that incorporating GIS into classroom practice depends not merely on the availability of the tool, but on professional autonomy, a supportive institutional environment, and sustained methodological guidance. Moreover, the institutional conditions for implementing a “new program” at the school level are identified as crucial. [24]

This argument closely aligns with the whole-school literature: in the absence of supportive organizational structures and collaborative professional knowledge creation, ESD/GIS initiatives risk remaining isolated practices driven by individual enthusiasts rather than becoming systemic, sustainable change.[25]

Empirical studies indicate that a “baseline capacity” for GIS already exists in Kazakhstan. For example, in a survey involving 133 geography teachers, 86.8% of respondents reported being familiar with GIS, although access to different GIS platforms was shown to vary considerably.[26] Other studies conducted in Kazakhstan also describe teachers’ use of geospatial technologies, including mobile GIS applications and reliance on various digital platforms in classroom practice.[27]

However, regional analytical reports conclude that in Kazakhstan, climate and sustainable development content is often introduced “horizontally” across subjects. At the same time, the existing subject-based curriculum structure complicates interdisciplinary integration and increases the risk that sustainability themes become compartmentalized within “environmental education,” rather than embedded systemically across disciplines.[28] This represents an important piece of evidence: even when integrative tools such as GIS are available, practice is likely to remain fragmented if there is no shared sustainability framework embedded within school governance and monitoring systems.

At this point, the scientific significance of the concept of “school mapping” becomes clearer. School mapping views GIS not merely as a classroom task, but as a data infrastructure that consolidates a school’s sustainability-related indicators — including operations, learning outcomes, and community engagement — into a unified map-based dashboard that feeds back into governance and decision-making processes.

This logic aligns closely with UNESCO’s green school quality standard, particularly its principles of monitoring and evaluation, as well as its emphasis on whole-school transformative change.[29]

Comparison with International Whole-School Models and the Nature of Fragmentation in Kazakhstan

To compare the situation in Kazakhstan with international models, the analysis draws primarily on UNESCO’s green school quality standard (four dimensions), as well as on the common features logic characteristic of widely implemented whole-school programs.[30] In addition, an empirical model that measures the whole-school approach through indicators of school organizational quality (based on teacher surveys) was used to demonstrate the significance of institutional factors.[31]

The table below compares the mandatory components identified in international whole-school models with the features observable in Kazakhstan’s geography curriculum and policy environment.

Table: International Whole-School SDG/ESD Integration Models and the Situation in Kazakhstan (Geography Focus)

Comparison Dimension	How International Best Practice Describes It	What Is Observed in Kazakhstan (Based on Available Evidence)	Specific Gap
(Governance)	Sustainability goals are embedded in the school strategy; roles and responsibilities are clearly defined; and a planning–monitoring cycle is implemented. [30]	The 2023–2029 Education Development Concept promotes a competence-based approach, STEM, and the improvement of assessment systems; however, the lack of systematic, planned implementation of monitoring-study recommendations at the regional level is identified as a “problem.” [13]	At the school level, SDG-linked governance indicators, planning, and reporting are not standardized, indicating weak coordination.
Teaching and Learning Outcomes	SDG learning objectives are operationalized as: competencies → lesson scenarios → assessment rubrics. [4]	The geography curriculum includes objectives related to global challenges, environmental protection, and the development of spatial thinking. [3]	Systematic mapping of learning objectives to SDG indicators and the availability of competency-based assessment tools are insufficient.
Infrastructure / Operations	School data on water, energy, waste, safety, and related operations are linked to learning content; audits are conducted, and monitoring is carried out annually. [22]	The Education Concept includes ideas of monitoring and database integration; however, the geography curriculum does not clearly specify procedures for systematically transforming school operational data into mandatory learning tasks. [32]	The “walk-the-talk” logic (learning through school practice) is not systematically integrated with geography.
Community and Partnerships	Community partnerships are a core pillar of the whole-school model; they promote joint action on local SDG-related issues. коммунікація кушейтіледі [33]	Regional reports highlight subject-based compartmentalization, which may hinder the integration of partnerships into a unified school strategy. [28]	There is an insufficient shared SDG map/indicator “common language” that connects community partnerships with classroom projects.
GIS and Data Culture	GIS strengthens learning outcomes, but sustainable implementation Teacher training and organizational support are required [34]	Remote sensing and GIS are included in the Grade 9 curriculum; teachers are aware of GIS is present; however, access and support are uneven. [35]	A “school mapping” design that links GIS to school governance and There is no school mapping design (SDG School Mapping Model) in place.

The main diagnosis emerging from this comparison is that, in Kazakhstan, geography as a subject is capable of providing SDG-related content and tools (such as spatial thinking and GIS components). However, at the level of the school as an organization — including governance, operations, community engagement, and monitoring — the cross-cutting mechanism that would integrate the SDGs into a coherent system remains weak.[36]

The short diagram below visually summarizes this diagnosis. The scores shown are indicative (0–3), and the sources underlying each dimension are indicated alongside them.

Diagram: Indicative Level of SDG Integration in Kazakhstan’s School Geography Across Whole-School Dimensions (0–3)

(0 = absent / not visible; 1 = episodic; 2 = present but systemically weak; 3 = institutionalized)

- Teaching Content (implicit sustainable development / ecology / global issues): **2** [37]
- Curricular space for GIS / spatial methods: **2** (әсіпесе 9-сыныпта) [16]
- Governance and regional coordination (implementation of recommendations): **1** [13]
- Linking infrastructure and operations with the learning process: **1** [38]
- Managing community partnerships through SDG indicators: **1** [39]
- Monitoring and evaluation with a data dashboard (SDG indicators): **1** [40]

Research Gap and Scientific Rationale for the SDG School Mapping Model

The above synthesis makes it possible to formulate the research gap in Kazakhstan in one concise statement as follows:

In Kazakhstan, the geography curriculum includes sustainability-related content and, at the Grade 9 level, components on GIS and remote sensing. However, in alignment with UNESCO’s Whole-School Approach principles, a systematic SDG School Mapping Model that integrates curriculum content, governance, operations, and competency assessment at the school level has not been operationalized. As a result, SDG integration remains fragmented, and regional and intra-school coordination continues to be weak.[41]

This represents precisely a model-level gap in terms of design science and implementation research. More specifically:

1. SDG Curriculum Mapping Gap:

Although UNESCO’s SDG learning objectives framework provides specific learning goals and suggested actions for each SDG, the learning objectives in Kazakhstan’s school geography curriculum have not been systematically mapped into a matrix aligned with SDG goals and indicators.[42]

2) Institutional Coordination Gap:

The national policy document acknowledges that, at the regional level, the implementation of international and monitoring-based recommendations lacks systematic planning. This indicates that a shared governance and monitoring mechanism for schools is insufficiently developed.[13]

3) Risk of GIS Remaining at the “Instructional Tool” Level:

Systematic reviews demonstrate that GIS is effective; however, the depth of its integration is uneven. This risk may also be present in Kazakhstan. Therefore, GIS should be linked to the whole-school governance and monitoring cycle rather than remaining solely a classroom-level instructional tool.[43]

4) Gap in School-Level Data–Indicator Architecture:

UNESCO’s green school standard promotes an “audit–plan–monitor” cycle; however, there is a lack of a scalable school-level architecture that integrates this cycle with GIS and spatial thinking in geography — specifically, a coherent framework combining a school map, an indicator dashboard, and aligned assessment tools.[44]

Goal: With its call to make every learner climate-ready, the Greening Education Partnership brings together various partners including Member States, intergovernmental organizations and CSOs as well as entities running the accreditation schemes, with the goal of transforming at least 50% of schools, colleges and universities into Green Schools by 2030.

Dimension	Qualitative outcome
School governance	Schools have a comprehensive Green School vision and policy that engages the school community through inclusive decision-making and active engagement to combat climate change, optimize resource management, enhance resilience and foster sustainable practices.
Facilities and operation	Schools have reduced risk through climate-proofing and improving emergency preparedness, as well as actively fostering sustainable practices in school (including energy and water use, waste management and procurement), especially by engaging learners in monitoring the school's progress. This promotes responsibility, climate resilience, health and well-being while inspiring sustainable choices within the school community.
Teaching and learning	Schools have incorporated ESD and climate change education in the curriculum demonstrating commitment to holistic learner development and equipping learners with skills to engage with their communities. <i>(For more in-depth guidance follow the Greening Curriculum Guidance)</i>
Community engagement	Schools raise community-wide awareness on climate change and preparedness, by empowering learners and engaging diverse stakeholders, through organized campaigns, promoting shared responsibility and sustainable practices to foster a culture of resilience and sustainability.

The target audience for this Standard are the organizers of the accreditation systems, who are essential facilitators of sustainable practices in educational environments.

Accreditation scheme organizers range from international associations, governments to non-profit/CSOs that provide official recognition and/or certification to schools based on their actions on ESD, in particular climate change education. These scheme organizers promote ESD and climate-readiness in schools, provide support to achieve those goals, and, in some measure, certify a school by benchmarking and tracking progress.

In addition, the Standard informs accreditation scheme implementers such as education authorities at different levels, CSOs, schools, universities and community learning centres as well as policy-makers at large in developing education and climate change policies for school.

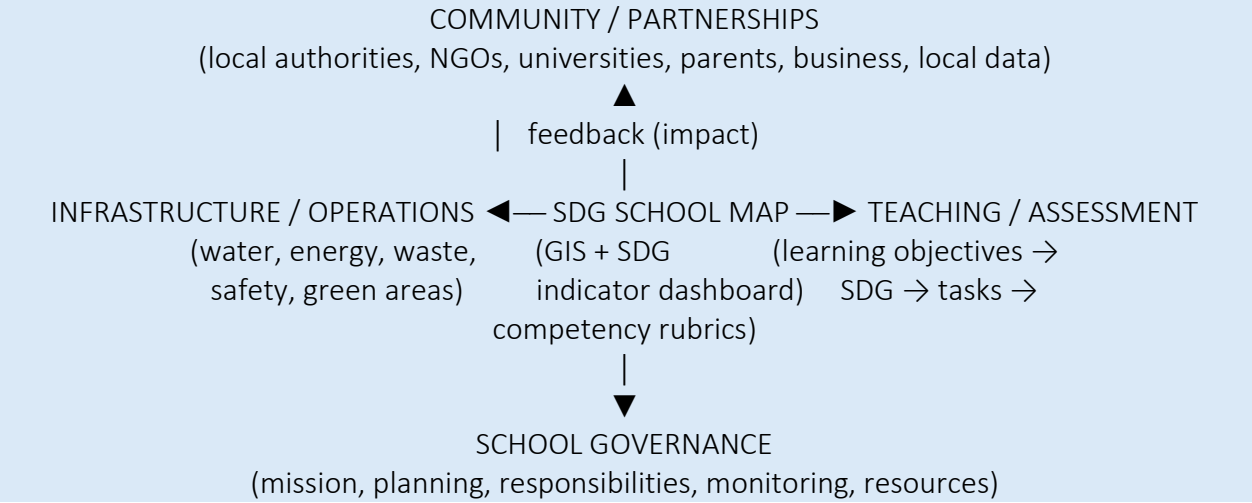
Figure 7. Key dimensions and qualitative outcomes of UNESCO’s Green School Quality Standard, outlining governance, operations, teaching and learning, and community engagement components for institutional SDG implementation.

To address these gaps, the SDG School Mapping Model must bridge “two worlds”:

- (a) the institutional logic of UNESCO’s whole-school standards, and
- (b) the spatial and data-driven methodology of geography as a discipline.

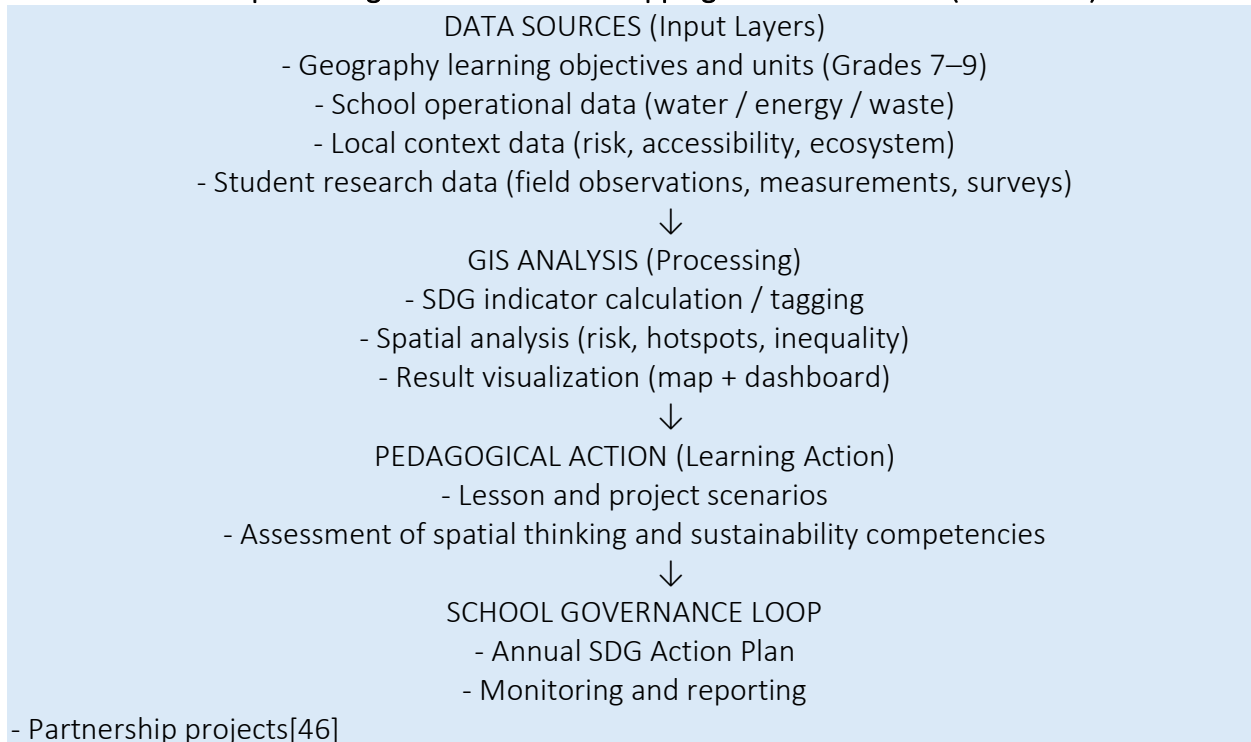
Below are two conceptual diagrams of the proposed model.

Conceptual Diagram: Whole-School Approach (WSA) Architecture Adapted for Geography



[45]

Conceptual Diagram: SDG School Mapping Model Data Flow (GIS-Based)



Research Questions, Objectives, and Implementation Directions for Kazakhstan

The doctoral-level research program addressing the gaps identified in this report may be structured as follows.

Research Questions

- 1) Through what methodology can the learning objectives of Kazakhstan's school geography curriculum (Grades 7–9) be systematically aligned with UNESCO's SDG learning objectives framework (SDG curriculum mapping), and at which levels (topic–lesson–project–assessment) can this alignment function sustainably?[47]
- 2) At the school level, what institutional readiness indicators should be defined for SDG integration in line with UNESCO's green school quality standard dimensions (governance; teaching & learning; facilities & operations; community partnerships), and what are the main "breakpoints" in the Kazakhstan context?[48]
- 3) When a GIS-based SDG School Mapping Model is implemented, through which mechanisms do students' spatial thinking and sustainability-related competencies develop, and which valid assessment instruments can be used to measure these outcomes?[49]
- 4) How do the factors determining the sustainability of GIS implementation at the teacher and school organizational levels (teacher agency, technical support, curriculum positioning, professional community) manifest in Kazakhstan, and which implementation strategy would be most effective?[50]

General Aim of the Study

To design, pilot, and validate a scalable SDG School Mapping Model that integrates UNESCO's Whole-School Approach principles with subject-specific geography content, GIS-based school mapping, and competency-based assessment tools in Kazakhstan's secondary school geography education.[51]

Specific Objectives (Tasks)

- To develop a nationally contextualized SDG curriculum matrix that aligns geography curriculum content with SDG goals and indicators (topic → SDG → indicator → task → assessment).[52]
- To design and pilot an institutional readiness diagnostic framework at the school level to measure whole-school dimensions (governance, organizational structures, professional development, partnerships, monitoring).[53]
- To develop a GIS-based SDG School Map and indicator dashboard prototype, including data layers, calculation logic, visualization design, and data ethics principles (data quality, privacy, and representativeness).[54]
- To evaluate the model's impact on learning outcomes, spatial thinking, and school-level coordination using a mixed-methods design (content analysis + teacher surveys/interviews + quasi-experimental or comparative pilot study).[55]

Implementation Directions for Kazakhstan

Taking into account the competence-based approach and the identified monitoring challenges in the national Education Development Concept, it is proposed to structure implementation as a **three-tier design**:

1. **Minimum Package** – introduction of a GIS + SDG mapping module at the Grade 9 level;
2. **School-Level Package** – integration of operational data (water, energy, waste) with learning projects and an SDG-based governance plan;
3. **District/Regional Package** – standardized indicators, professional communities of practice, and regional-level monitoring mechanisms.

This direction aims to transform the policy-level diagnosis of weak, non-systematic implementation of recommendations in the regions into a structured, model-based solution.
[56]

Conclusion

This study has identified a critical design-level gap in the integration of the Sustainable Development Goals (SDGs) into school geography education in Kazakhstan. While sustainability-related content, global issues, and GIS components are present within the curriculum—particularly at the Grade 9 level—the integration remains largely implicit and fragmented. At the institutional level, there is no systematic mechanism that aligns curriculum content, governance, school operations, community partnerships, and monitoring within a unified SDG framework consistent with UNESCO's Whole-School Approach.

The analysis demonstrates that geography as a discipline possesses strong conceptual and methodological potential to serve as an anchor subject for SDG integration. Its emphasis on spatial thinking, human–nature–society systems, and GIS-based analysis provides a solid epistemological foundation for operationalizing sustainability education. However, without a cross-cutting institutional architecture that connects these disciplinary strengths to school governance and monitoring cycles, SDG integration risks remaining episodic and dependent on individual teacher initiative.

To address this gap, the study proposes the development and pilot implementation of an SDG School Mapping Model that bridges two domains: the institutional logic of UNESCO’s whole-school standards (governance, teaching and learning, facilities and operations, community partnerships, monitoring), and the spatial-data methodology of geography supported by GIS. The model conceptualizes school mapping not merely as a pedagogical tool, but as a data infrastructure that integrates operational indicators, learning outcomes, and community engagement into a coherent monitoring and decision-support system.

The proposed three-tier implementation strategy (minimum module, school-level package, and regional coordination package) offers a scalable pathway for translating national policy objectives into school-level practice. By institutionalizing SDG–curriculum mapping, establishing readiness diagnostics, and embedding GIS-based indicator dashboards into governance processes, the model aims to transform fragmented sustainability efforts into a measurable and coordinated system.

Ultimately, the SDG School Mapping Model contributes to both theory and practice: theoretically, it advances implementation research in whole-school sustainability by introducing a spatially grounded design architecture; practically, it provides Kazakhstan’s education system with a scalable mechanism for aligning geography education with national development priorities and global sustainability commitments.

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Professional-Oriented Methodology for Teaching Chemistry in a Medical College for Nursing Students

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Abstract

The modernization of vocational medical education requires a shift from content-based instruction to competence-oriented professional training. Chemistry, as a foundational discipline in medical colleges, often remains theoretical and detached from nursing practice, which reduces students' motivation and limits professional application. This study proposes a professional-oriented methodology for teaching chemistry to nursing students in medical colleges, integrating clinical context, case-based learning, simulation, and interdisciplinary alignment with medical subjects.

The purpose of the research is to develop and justify an instructional model that contextualizes chemical knowledge within nursing practice and enhances professional competence formation. The methodology is based on contextual learning theory, competency-based education, and interdisciplinary integration principles. A quasi-experimental design was implemented with first-year nursing students in a medical college. Quantitative and qualitative data were collected through diagnostic testing, surveys, and performance-based assessments.

The findings demonstrate that professionally contextualized chemistry instruction significantly improves students' conceptual understanding, motivation, and ability to apply chemical knowledge in clinical scenarios. Students exposed to the proposed model showed higher levels of professional reasoning, pharmacological comprehension, and analytical thinking compared to those in traditional instruction.

The study concludes that integrating professional nursing tasks into chemistry teaching enhances vocational relevance and strengthens interdisciplinary connections between chemistry and medical sciences. The model can be recommended for implementation in medical colleges aiming to improve the quality of nursing education.

Keywords: vocational education, nursing education, professional-oriented teaching, chemistry instruction, competency-based approach, medical college.

Introduction

The rapid development of healthcare systems worldwide demands highly qualified nursing professionals capable of applying scientific knowledge in clinical decision-making. Modern nursing practice requires understanding biochemical processes, pharmacological interactions, sterilization chemistry, solution preparation, electrolyte balance, and acid-base regulation. However, in many medical colleges, chemistry is still taught as a general academic discipline rather than as a professional foundation for nursing practice.

Traditional chemistry instruction often emphasizes abstract formulas, theoretical equations, and laboratory techniques disconnected from medical realities. As a result, nursing students frequently perceive chemistry as difficult and irrelevant to their future profession. This gap between theoretical content and professional application negatively affects motivation, academic achievement, and competency development.

Professional-oriented education aims to align subject content with future occupational tasks. In the context of nursing education, chemistry should not be taught as an isolated scientific discipline but as a tool for understanding clinical processes such as drug dilution, intravenous solution preparation, disinfection procedures, metabolism, and laboratory diagnostics. Therefore, revising the methodology of teaching chemistry in medical colleges becomes an urgent pedagogical task.

Competency-based education frameworks emphasize learning outcomes related to professional performance. Nursing competencies include clinical reasoning, patient safety awareness, accurate dosage calculation, and understanding biochemical indicators. These competencies require a solid chemical foundation integrated with medical context. Without such integration, subject knowledge remains fragmented and superficial.

The purpose of this study is to develop and justify a professional-oriented methodology for teaching chemistry to nursing students in medical colleges. The proposed model integrates contextual learning, interdisciplinary collaboration, case-based instruction, and simulation-based activities to bridge the gap between theory and practice.

The research addresses the following questions:

1. How can chemistry content be restructured to reflect nursing professional tasks?
2. What instructional strategies enhance the professional relevance of chemistry?
3. Does professional contextualization improve learning outcomes and motivation?

By transforming chemistry instruction into a professionally meaningful component of nursing education, medical colleges can strengthen students' readiness for clinical practice and improve overall educational quality.

Theoretical Framework

The theoretical foundation of this study is based on three interconnected pedagogical approaches: contextual learning theory, competency-based education, and interdisciplinary integration.

Contextual learning theory suggests that knowledge becomes meaningful when students see its relevance to real-life situations. According to this approach, learning occurs more effectively when academic content is embedded in authentic professional contexts. In nursing education, contextualization involves presenting chemical concepts through clinical scenarios such as electrolyte imbalance, acid-base disorders, drug stability, and sterilization chemistry.

Competency-based education emphasizes measurable learning outcomes aligned with professional standards. In nursing programs, competencies include patient safety, pharmacological accuracy, clinical decision-making, and analytical reasoning. Chemistry instruction must contribute directly to these competencies by focusing on practical chemical applications rather than purely theoretical abstraction.

Interdisciplinary integration plays a crucial role in vocational education. Chemistry intersects with anatomy, physiology, microbiology, pharmacology, and clinical practice. For example:

- Acid-base balance relates to blood pH regulation.
- Solutions and concentration calculations connect to intravenous therapy.
- Organic chemistry principles explain drug structure and metabolism.
- Oxidation-reduction reactions are linked to cellular respiration and antiseptic action.

Another important theoretical principle is problem-based learning (PBL). PBL encourages students to analyze clinical cases requiring chemical reasoning. For instance, students may calculate medication dilution, interpret laboratory values, or analyze disinfection procedures. This strategy develops critical thinking and professional judgment.

Simulation-based learning also supports vocational preparation. By using laboratory simulations that imitate clinical procedures (e.g., preparing saline solutions or calculating glucose infusion rates), students actively connect chemistry knowledge with nursing tasks.

Thus, the theoretical framework supports transforming chemistry teaching from content transmission into professional competence development through contextual, interdisciplinary, and problem-oriented methods.

Results

The professional-oriented methodology was implemented with first-year nursing students (N=60) in a medical college. Two groups were formed: an experimental group (professional-oriented instruction) and a control group (traditional instruction).

1. Academic Achievement

Pre-test results indicated similar baseline knowledge levels in both groups. After one semester, post-test analysis showed significant differences. The experimental group demonstrated:

- 25% higher performance in concentration calculations.
- 30% improvement in understanding acid-base balance.
- 28% better results in applied problem-solving tasks.

Students were better able to explain chemical processes related to clinical situations.

2. Motivation and Professional Relevance

Survey data revealed that 82% of students in the experimental group considered chemistry directly relevant to nursing practice, compared to 46% in the control group. Students reported increased confidence in performing medication calculations and understanding laboratory indicators.

Many students emphasized that case-based tasks and clinical examples helped them “see chemistry in real medical life.” The connection between chemical theory and patient care enhanced intrinsic motivation.

3. Development of Professional Competencies

Performance-based assessments demonstrated improved competency indicators:

- Accurate drug dilution calculations.
- Correct preparation of isotonic solutions.
- Analytical interpretation of electrolyte imbalance cases.
- Understanding chemical safety in sterilization procedures.

Students in the experimental group showed stronger interdisciplinary thinking, linking chemical reactions to physiological processes.

4. Teacher Observations

Instructors observed higher engagement levels during contextual lessons. Group discussions around clinical cases stimulated collaborative problem-solving. Students asked more professional questions related to pharmacology and patient safety.

5. Qualitative Insights

Focus group interviews revealed that students valued:

- Simulation-based practical tasks.
- Integration with medical subjects.
- Real hospital-related examples.

They reported reduced anxiety toward chemistry and greater readiness for clinical training.

Overall, the results confirm that professional-oriented chemistry teaching enhances academic achievement, motivation, and competency development in nursing education.

Conclusion

The study demonstrates that teaching chemistry in medical colleges through a professional-oriented methodology significantly enhances nursing students' academic performance, motivation, and professional competence formation. Contextual learning, interdisciplinary integration, case-based instruction, and simulation-based activities effectively bridge the gap between theoretical chemistry and clinical nursing practice.

By aligning chemical content with professional nursing tasks, educators can transform chemistry from an abstract academic subject into a practical scientific foundation for patient care. The proposed model supports competency-based education standards and strengthens interdisciplinary coherence within medical curricula.

The findings suggest that vocational institutions should revise chemistry syllabi to emphasize clinical relevance, applied problem-solving, and professional contextualization. Future research may explore digital simulations and AI-supported adaptive learning in professional chemistry education for medical students.

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БАСТАУЫШ СЫНЫП ОҚУШЫЛАРЫНЫҢ МАТЕМАТИКА САБАҚТАРЫНДА ЛОГИКАЛЫҚ ОЙЛАУ ҚАБІЛЕТТЕРІН ДАМУ ЖОЛДАРЫ

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Аңдатпа

Бұл мақалада бастауыш сынып оқушыларының критикалық ойлауын дамытудағы логикалық есептердің маңызы мен тиімділігі жан-жақты қарастырылады. Логикалық есептер балалардың танымдық белсенділігін арттырып, мәселеге сан қырлы көзқараспен қарауға, шешім қабылдау барысында дәлелді ой айтуға, өз пікірін қорғауға және жаңаша ойлау қабілетін дамытуға көмектеседі. Мақалада логикалық есептердің түрлері, оларды оқытуда қолдану әдістері, нақты мысалдар мен зерттеу нәтижелері негізінде логикалық тапсырмалардың оқушылар дамуына әсері көрсетіледі. Сонымен қатар логикалық есептер арқылы оқушылардың математикалық сауаттылығы, шығармашылық ойлау және ынтымақтастықта жұмыс жасау дағдыларының дамуы талқыланады.

Тірек сөздер: логикалық есептер, бастауыш сынып, критикалық ойлау, зияткерлік қабілет, танымдық даму, шығармашылық.

Кіріспе

Қазіргі заман – жылдам өзгерістер мен жаңаша ойлауды талап ететін уақыт. ХХІ ғасырда адамзат алдында тұрған басты міндеттердің бірі – сыни (критикалық) тұрғыдан ойлай алатын, логикалық әрі шығармашылықпен әрекет ететін тұлға тәрбиелеу. Бұл міндет мектеп қабырғасынан бастап жүзеге асырылуы қажет. Әсіресе бастауыш сынып кезеңі – баланың ойлау, есте сақтау, зерделеу қабілеттері қарқынды дамитын маңызды уақыт. Осы кезеңде баланың бойында өмірге қажетті дағдыларды қалыптастыру үшін тиімді әдістерді дұрыс таңдау қажет.

Солардың бірі – логикалық есептерді қолдану. Логикалық есептер тек математикамен шектелмей, оқушылардың дүниетанымын кеңейтеді, күнделікті өмірдегі мәселелерді талдай алуға, түрлі шешім қабылдауға, шығармашылықпен ойлануға жетелейді. Логикалық тапсырмалар – ойлауды дамытудың қуатты құралы, ал оларды жүйелі қолдану – оқушылардың интеллектуалдық әлеуетін арттыратын жолдардың бірі.

Негізгі бөлім

Критикалық ойлау – бұл ақпаратты талдау, бағалау және өзіндік қорытынды жасау үдерісі. Д.Эннис (1987) бойынша, критикалық ойлау – дәлелдерді мұқият зерттеп, өз пікіріңді логикалық тұрғыдан негіздеу қабілеті. Бастауыш мектеп жасында бұл дағдының қалыптасуы кейінгі білім алу кезеңінде табысты болуға ықпал етеді.

Логикалық есептердің педагогикалық рөлі

Логикалық есептер – оқушылардың ойлау операцияларын (талдау, синтез, салыстыру, жалпылау, абстракция) белсенді түрде іске қосатын тапсырмалар. Олар:

- Шығармашылық пен логиканы ұштастырады,
- Мәселені шешуге бағыттайды,
- Ереже мен үлгілерді табуға үйретеді,
- Өзіндік қорытынды шығаруға дағдыландырады.

Білім беру процесіне логикалық есептерді жүйелі енгізу оқушылардың ақпаратты қабылдау және өңдеу дағдыларын, сонымен бірге мәселені түрлі қырынан қарау қабілетін дамытады.

Әдістер

Зерттеу «Бақыршық орта мектеб» КММ базасында өткізілді: *зерттеуге 2 сыныптың 13 оқушысы қатысты.*

Мақалада логикалық есептердің бастауыш сынып оқушыларының критикалық ойлауын дамытудағы рөлін зерттеу үшін төмендегі әдістер қолданылды:

1. “Логикалық есептер бойынша оқушылардың қызығушылығы мен көзқарасын анықтау” сауалнамасы

Мақсаты: бастауыш сынып оқушыларының логикалық есептерге деген қызығушылығын, көзқарасын, қалай шешетіні және қиындыққа тап болғандағы әрекетін анықтау. Сонымен қатар, логикалық есептерді ойын арқылы шешудің тиімділігін бағалау көзделді.

Өткізу барысы:

Сауалнамаға 13 бастауыш сынып оқушысы қатысты. Сауалнама 10 сұрақтан тұрып, жабық (иә/жоқ), жартылай ашық және ашық сұрақтар түрінде құрылды. Оқушылар сұрақтарға өз бетінше, кей жағдайда мұғалімнің көмегімен жауап берді. Жинақталған жауаптар сараланып, мынадай нәтижелерге қол жеткізілді:

Нәтижелер мен талдау:

1. Есеп шығаруға деген қызығушылық

92% оқушы есеп шығарғанды «Иә» деп жауап берді, бұл олардың математикалық ойлауға бейімділігін көрсетеді.

2. Ұнайтын есеп түрлері

Оқушылардың көпшілігіне жұмбақтар және басқатырғыштар ұнайды екен. Бұл олардың шығармашылық ойлау мен логикаға қызығушылығын білдіреді.

3. Оңай есеп түрлері

Көптеген балалар суреттермен берілген есептерді және қосуды қажет ететін есептерді оңай деп тапты. Бұл бастауыш деңгейге тән қабылдауға сәйкес келеді.

4. Қиын есеппен кездесу жағдайында

23% бала басқа жол іздейтінін, 77% достарынан немесе мұғалімнен сұрайтынын айтты. Бұл балалардың шыдамдылығы мен ынтасының жоғары екенін көрсетеді. Ешқай бала тапсырманы тастап кететінін айтқан.

5. Логикалық есептермен таныстығы

76% оқушы бұрын логикалық есептер шығарып көргенін айтты. Есте қалған есептер ішінде жұмбақтар, математикалық басқатырғыштар, сандар қатары жиі аталды.

6. Мысал есепке жауап (мысықтар есебі)

61% оқушы дұрыс шешім тауып (4 мысық), ал кейбіреулері шатасып, 7 немесе 16 деп жауап берді. Бұл логикалық тапсырманың сыни ойлауды қажет ететінін дәлелдейді.

7. Қалай шешкен ұнайды?

Балалардың көбі есепті ойлап, сурет салып немесе достарымен бірге шешкенді ұнатады. Бұл бірлескен оқу мен визуалды қабылдаудың маңызын көрсетеді.

8. Қиын есепке реакция

84% бала шешуге тырысатынын немесе көмек сұрайтынын айтты. Бұл балаларда табандылық пен ынта бар екенін білдіреді.

9. Логикалық есепті ойын түрінде шешу туралы пікір

Барлық оқушылар дерлік (94%) “иә” деп жауап беріп, логикалық ойын элементтерін қызықты деп тапқан.

Сауалнама нәтижесіне сүйенсек, бастауыш сынып оқушылары логикалық есептерді қызығушылықпен қабылдайды. Олар қиындық туындағанда әртүрлі жолмен шешуге тырысады, бұл олардың сыни және креативті ойлау дағдыларының қалыптасып келе жатқанын көрсетеді.

2.«Сандар көпірі» әдісі

Мақсаты:

- Бірдей сандарды сызық арқылы қосу арқылы оқушылардың логикалық ойлау және кеңістіктік бейнелеу дағдыларын дамыту.
- Сызықтардың бір-бірімен қиылысу мүмкін еместігі шарты арқылы жоспарлау мен сыни тұрғыдан ойлау қабілетін шыңдау.
- Топ ішінде бірлесіп жұмыс істеу арқылы ұжымдық талқылау мен пікір алмасу мәдениетін қалыптастыру.

Өткізу барысы:

Әр жұпқа түрлі-түсті квадраттарда жазылған 1, 2, 3 сандары көрсетілген кесте таратылды. Шарт: әрбір бірдей санды сызық арқылы жалғау, бірақ сызықтар еш жерде қиылыспауы тиіс. Алдымен жеке-жеке 3 минут ішінде шешім табуға уақыт берілді, кейін топ ішінде өзара салыстырып, ең оңтайлы жолды ортаға шығарды.

Нәтижелер:

- ❖ Барлық оқушылар (100 %) тапсырманы дұрыс орындап, сандарды қиылмайтын сызықтар арқылы қосты.
- ❖ Оқушылардың жұмысына баға беру кезінде келесі дағдылар байқалды:
- ❖ Жоспар құрғандағы икемділік: кейбір оқушылар алдымен ең үлкен арақашықтықтағы сандарды жалғап, содан соң қалғандарын шешті.
- ❖ Балама жолдарды іздеу: кейбір топтар бірдей санды жалғау үшін бірнеше нұсқаны қарастырып, ең қысқа жолды таңдады.
- ❖ Коммуникация: топ ішінде идеяларымен бөлісіп, бір-бірінің шешімін жақсартты.

«Сандар көпірі» – бастауыш сынып оқушыларының логикалық ойлауын, сыни талдауын және жоспарлау дағдыларын дамытуға арналған тиімді жаттығу. Барлық оқушылар тапсырманы қызыға орындап, бірлесіп шешім таба білді. Бұл жаттығуды оқу бағдарламасына жүйелі түрде енгізу балалардың ойлау мәдениетін байытады.

3. «Құпия пішіндер» әдісі

Мақсат:

- Балалардың логикалық ойлау қабілетін дамыту
- Символдарды (пішіндерді) сандармен ауыстырып, теңдеулерді шешуге үйрету
- Математикалық амалдарды (қосу, азайту) дұрыс орындау дағдыларын қалыптастыру
- Зейінділік пен назар аударуын арттыру

Барысы:

Оқушыларға бірнеше қатардан тұратын математикалық теңдеулер беріледі. Әрбір қатарда фигуралар (үшбұрыш, шаршы, т.б.) арқылы белгіленген сандар бар. Балалар бұл фигуралардың нақты мәнін табу керек.

Талдау:

Бірінші жол: $\text{үшбұрыш} + \text{үшбұрыш} + \text{үшбұрыш} = 30$

Бұл жерде: $10 + 10 + 10 = 30$, демек: $\text{үшбұрыш} = 10$

Екінші жол: үшбұрыш + шаршы + шаршы = 18

$10 + \text{шаршы} + \text{шаршы} = 18 \rightarrow \text{шаршы} = 4$

Үшінші жол: шаршы - 2 = 2 $\rightarrow 4 - 2 = 2 \rightarrow$ бәрі дұрыс

Төртінші жол: үшбұрыш + шаршы + 2 = ?

$10 + 4 + 2 = 16$

Қорытынды:

- Тапсырманы 5 бала дұрыс орындады: әр фигураның мәні дұрыс анықталды. Ал кейбіреулері шатасып, 25 немесе 17 деп жауап берді. Бұл логикалық тапсырманың сыни ойлауды қажет ететінін дәлелдейді.
- Бұл тапсырма балаларға абстрактілі ойлауға, есепті бөлшектеп шешуге және математикалық тұжырым жасауға мүмкіндік береді.
- Сонымен қатар, топтық жұмыс кезінде балалар бір-бірімен ақылдасып, пікір алмасу арқылы ұжымдық шешім қабылдауды үйренеді.

4. «Сиқырлы Пирамида» әдісі

Мақсат:

- Балалардың логикалық ойлау қабілетін және зейінін дамыту
- Сандық қатарларды талдау және салыстыру арқылы қисынды шешімдер қабылдауға үйрету
- Комбинаторика элементтерін қолдануға баулу
- Топта немесе жеке жұмыс істеу арқылы шығармашылық ойлау мен шыдамдылықты дамыту

Барысы:

Әр балаға үш деңгейлі пирамида құрылымы бар қағаз беріледі. Қағазда 6 бос шеңбер мен 6 сан (1-ден 6-ға дейін) болады. Мақсат – осы сандарды пирамиданың ішіндегі шеңберлерге орналастыру арқылы әр қабырғаның сандарының қосындысы бірдей (мысалы, 9 немесе 10) болатындай етіп орналастыру.

Шарты:

- ❖ Әр сан тек бір рет қолданылуы керек
- ❖ Үш қабырғаның қосындысы бірдей санға тең болуы қажет (мысалы, бір ойында 9, келесіде 10 деп белгіленеді)
- ❖ Балалар өз бетімен жұмыс істейді

Мысал: егер 3 қабырғалы пирамида құрылса және сандар 1-ден 6-ға дейін болса, келесі үлгі дұрыс болуы мүмкін (мысалы, егер қосынды 10 болса):

- $3 + 2 + 5 = 10$
- $5 + 1 + 4 = 10$
- $4 + 6 + 0 = 10$ (мысал ретінде, нақты шешім комбинация арқылы табылады)

Нәтиже: 9 санын- 53% оқушы дұрыс шығара алды; 10 санын- 92% оқушы дұрыс шығарды.

Қорытынды:

- Балалар қиындыққа қарамастан табандылықпен жұмыс істеді
- Көпшілігі логикалық қатынастарды түсініп, сандарды дұрыс орналастыра алды
- Бұл ойын арқылы: ойлау, талдау, салыстыру дағдылары дамыды
- Кейбір балалар шығармашылықпен ойлауға тырысты
- Балалардың арасында пікір алмасу, көмек көрсету, топтық жұмыс жасау байқалды

5. «Логикалық есептер» тесті

Мақсаты:

- Оқушылардың логикалық ойлау қабілеттерін дамыту.
- Қателіктер мен жалған түсініктерді анықтап, оларды түзету.

- Оқушылардың абстрактілі ойлау дағдыларын жақсарту.

Барысы:

Барлық оқушыға осы сұрақтар көрсетіледі және дауыстап оқылады. Оқушылар сұрақтарға жауап береді және өз шешімдерін түсіндіреді. Мұғалім әр сұрақтың дұрыс жауабын талқылайды. Нәтижелерді шығару үшін, оқушылардың жауаптарын жинап, дұрыс жауаптарды тексеру керек.

Нәтижелерді шығару:

1. Әр оқушының дұрыс жауап берген сұрақтарының саны есептеледі.
2. Қате жауаптар талқыланады, және оқушыларға қай сұрақта қандай қателік кеткені көрсетіледі.
3. Нәтиже бойынша әр оқушының логикалық ойлау деңгейі бағаланады:
 - 6-7 дұрыс жауап – жоғары деңгей. (жоқ)
 - 4-5 дұрыс жауап – орташа деңгей.(53%)
 - 1-3 дұрыс жауап – төмен деңгей.(47%)

Қорытынды: қосымша жұмысты қажет етеді. Мұғалімдер оқушылардың қателіктерін талқылап, логикалық ойлауды дамытуға бағытталған жұмыстарды жалғастыруы тиіс.

Пікірталас

Логикалық есептер математикалық, вербалды және визуалды болып үшке бөлінеді. Әрқайсысының өз ерекшеліктері бар:

- Математикалық логикалық есептер – сандармен, теңдеулермен және амалдармен байланысты есептер.
- Вербалды логикалық есептер – сөздер арқылы берілетін логикалық тапсырмалар.
- Визуалды логикалық есептер – геометриялық пішіндер мен суреттерді қолдану арқылы ойлауды дамытатын есептер.

Зерттеу көрсеткендей, логикалық тапсырмалар дәстүрлі есептерге қарағанда оқушылардың қызығушылығын көбірек тудырады. Бұл олардың белсенділігін арттырып, оқу мотивациясын жоғарылатады. Алайда кейбір мұғалімдер мұндай есептерді сабақта жиі қолданбайды. Оның себептерінің бірі – оқулықтарда логикалық тапсырмалардың аз кездесуі және мұғалімдердің бұл бағыттағы әдістемелік дайындықтарының жеткіліксіздігі.

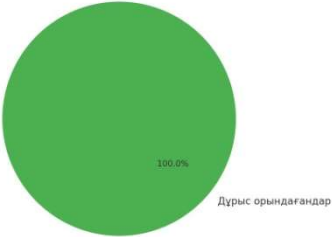
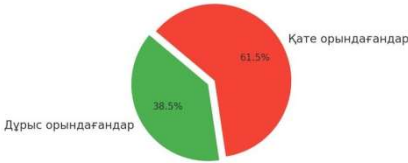
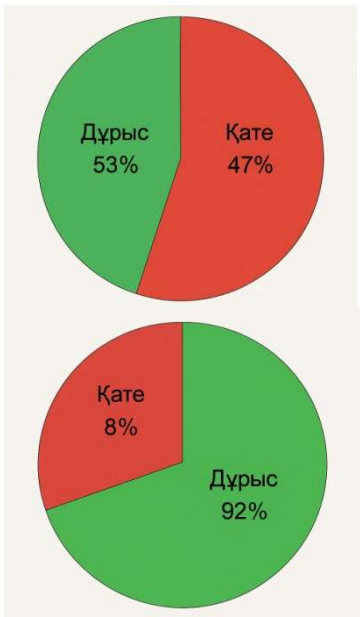
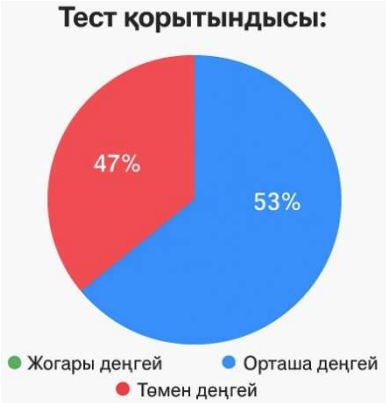
Логикалық есептерді бастауыш сыныпта қолдану келесі артықшылықтарды береді:

1. Критикалық ойлауды дамыту – оқушылар тек ережелерді жаттамай, мәселені жан-жақты қарастырып, шешім іздейді.
2. Шығармашылық қабілетті арттыру – стандартты емес ойлау дағдыларын қалыптастырады.
3. Зейінді шоғырландыру – есепті шешу барысында баланың назарын ұзақ уақыт бойы бір мәселені талқылауға бағыттайды.
4. Оқушылардың қызығушылығын арттыру – қызықты логикалық тапсырмалар арқылы балалардың математика мен ойлау процестеріне деген ынтасы артады.

Нәтижелер

Зерттеу барысында логикалық есептерді жүйелі түрде шешкен оқушылардың танымдық қабілеттері жақсарғаны анықталды. Тәжірибелік зерттеу нәтижелері келесіні көрсетті:

- Логикалық есептерді жиі қолданған оқушылар стандартты есептерді тез әрі тиімді шешеді.
- Оқушылар арасында аналитикалық ойлау дағдысы қалыптасып, тапсырмаларға әртүрлі қырынан қарау дағдылары дамыды.
- Ойын түрінде ұйымдастырылған логикалық есептер сабаққа деген қызығушылықты арттырды.

Тапсырманың атауы	Оқушылардың нәтижелері (%)	Қорытынды
«Сандар көпірі» әдісі		Логикалық ойлау, сыни тұрғыдан ойлау және жоспарлау дағдылары дамыды. Оқушылар бірлесіп шешім табуда белсенді болды.
«Құпия пішіндер» әдісі		Абстрактілі ойлау және математикалық амалдарда қателіктер орын алды. Тапсырма сыни ойлауды қажет етеді.
«Сиқырлы Пирамида» әдісі		Логикалық қатынастарды түсіну және сандарды дұрыс орналастыру дағдылары дамыды. Көбісі тапсырманы сәтті орындады.
«Логикалық есептер» тесті		Қосымша жұмыс қажет, мұғалімдер логикалық ойлау қабілетін дамытуға назар аударуы керек.

Ұсыныстар:

1. Логика аптасы:

Мектептерде немесе университеттерде жылына бір рет "Логика аптасын" өткізу – логикалық ойындар, жарыстар, дебаттар мен викториналар ұйымдастырылып, қатысушыларға сыйлықтар беріледі.

2. Логика пәні:

Бастауыш сыныптан бастап аптасына бір рет “Логикалық ойлау негіздері” атты арнайы пән енгізу.

3. Логика клубтары:

Әр мектепте “Логика және Шешендік” клубтарын ашып, логикалық есептер, шахмат, басқатырғыштар шешу арқылы ойлау қабілетін ұштау.

4. Логика марафоны:

Онлайн және оффлайн форматта бүкіл республика бойынша “Логика марафонын” өткізіп, жеңімпаздарға гранттар немесе курстар ұсыну.

5. Логика қосымшасы:

Оқушыларға арналған қазақ тіліндегі логикалық тапсырмалар мен ойындар жинақталған мобильді қосымша жасау.

6. Ата-аналармен бірлескен жұмыс:

Ата-аналармен бірлескен жұмыс жүргізіп, логикалық тапсырмаларды үйде де қолдануға бағыттау

7. Мұғалімдерге логика тренингі:

Мұғалімдерге арнайы логикалық ойлау тренингтері өткізіліп, сабақ берудің жаңа әдістерін меңгеруіне көмектесу.

8. Телевизиялық шоу:

Жасөспірімдер мен жастар арасында логикалық тапсырмалар мен жарыстардан құралған телешоу ұйымдастыру (мысалы: “Ойла, тап, жең!”).

9. Кітап сериясы:

“Логика әлемі” атты балалар мен жасөспірімдерге арналған түрлі деңгейдегі логикалық тапсырмалар кітабын шығару.

10. Логикалық олимпиада:

Жыл сайын “Ұлттық логикалық олимпиада” өткізу – түрлі жастағы қатысушыларға арналған деңгейлермен және ел астанасында финалмен аяқталатын ерекше форматта.

Қорытынды

Қорыта айтқанда, логикалық есептер – бастауыш сынып оқушыларының критикалық ойлау қабілетін дамытудың тиімді жолы. Оларды сабақ үдерісіне жүйелі енгізу арқылы оқушылардың зияткерлік әлеуетін арттыруға болады. Мұндай тапсырмалар арқылы балалар күрделі жағдайларда шешім қабылдауға, салыстыруға, логикалық пайымдауға үйренеді. Сондықтан логикалық есептер бастауыш сынып оқыту бағдарламасында маңызды орын алуы қажет.

Логикалық есептер бастауыш сынып оқушыларының критикалық ойлау қабілетін дамытудың тиімді әдістерінің бірі болып табылады. Бұл тапсырмалар оқушылардың зерделеу, салыстыру, талдау және қорытынды жасау сияқты ойлау әрекеттерін жетілдіреді. Логикалық есептер арқылы балалар өз ойларын нақты жеткізе білуге, дәлелдер келтіруге, бірнеше жолмен шешім табуға дағдыланады. Мұндай тапсырмалар баланың есте сақтау, зейін, ойлау жүйесін дамытуға ықпал етіп, оқу үрдісін қызықты әрі тиімді етеді. Сонымен қатар, логикалық есептер оқушылардың өз бетімен жұмыс жасауына, жауапкершілік пен табандылық танытуына мүмкіндік береді. Бұл тапсырмаларды жүйелі қолдану арқылы баланың зияткерлік әлеуеті дамып, өмірде кездесетін түрлі жағдайларда тиімді шешім қабылдай алатын тұлға қалыптасады.

Болашақта логикалық есептерді интерактивті оқыту әдістерімен біріктіру, цифрлық технологияларды пайдалану арқылы олардың тиімділігін одан әрі арттыруға болады.

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DEVELOPMENT OF AN ALGORITHM FOR MASTERING THE TOPIC BY STUDENTS USING STATISTICAL METHODS

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Abstract

This review article examines contemporary scientific approaches to the use of statistical methods for analyzing students' topic comprehension processes and modeling their learning trajectories. The study aims to identify the role of statistical physics methods in explaining learners' learning dynamics, detecting latent learning states, and constructing mastery algorithms. The review includes six recent studies published in the Scopus database over the past five years.

The analyzed works provide evidence for the effectiveness of Learning Analytics, Educational Data Mining, Hidden Markov Models, machine learning techniques, and statistical modeling in educational systems. According to the authors, students' learning behavior represents a complex, multilayered system whose dynamics can only be fully revealed through statistical models. The review highlights recurring learning difficulties, gaps in the application of statistical methods, and the theoretical foundations for predicting learning progress.

This review offers a theoretical and methodological basis for studies aimed at constructing algorithms for student topic mastery. The findings demonstrate that the use of statistical methods enhances learning quality, enables the modeling of learning trajectories, and provides objective evaluation of students' comprehension levels.

Keywords: Statistical methods; Learning trajectories; Mastery algorithm; Learning Analytics; Educational Data Mining; Hidden Markov Model; Statistical modeling; Physics education; Mastery level; Predictive modelling.

1. Introduction

In modern education, enhancing students' ability to master complex scientific content—particularly in physics, where the level of abstraction is high—has become a significant challenge. To understand and model students' learning processes more deeply, there is an increasing need to apply statistical methods, Learning Analytics (LA), and Educational Data Mining (EDM) tools. These methods allow for the analysis of learning behavior based on quantitative data, the identification of latent learning strategies, and the construction of mastery algorithms.

Over the past five years, numerous studies published in Scopus and WoS databases have demonstrated the effectiveness of statistical models—such as Hidden Markov Models (HMM), predictive modeling, machine learning (ML), and complex data-driven analytical techniques—in predicting student behavior, modeling learning profiles, and improving learning outcomes. The shared aim of these studies is to interpret students' learning trajectories and characterize their mastery levels in an algorithmic manner.

The purpose of this review article is to systematically analyze theoretical and practical research that enables the construction of a topic mastery algorithm using statistical methods.

2. Main Section

As indicated in the introduction, modeling students' topic mastery processes with statistical methods holds exceptional significance in contemporary education. To gain a deeper understanding of this phenomenon, numerous recent studies have explored the application of Learning Analytics, Educational Data Mining, predictive modeling, and statistical physics methods in educational contexts. These studies describe students' learning activities through quantitative data and reveal the algorithmic nature of their mastery dynamics.

The main section of this review analyzes six (6) scientific articles that examine the use of statistical methods to construct student mastery algorithms. Specifically, the studies of Paolucci, Minerva & Rossi (2024), Verykios et al. (2024), Flores et al. (2022), López-Meneses et al. (2025), Cocco (2022), and Baker (2020) are reviewed. These works are directly relevant to the research topic and provide both theoretical and methodological foundations for statistically modeling students' learning processes.

2.1 Analysis of the Article by Paolucci, Minerva, and Rossi (2024)

The work of *Paolucci, Minerva, and Rossi (2024)* represents one of the contemporary studies conducted within the field of Learning Analytics and focuses on analyzing students' learning processes through statistical methods. In this article, Learning Analytics is conceptualized not merely as a tool for collecting data or generating numerical indicators, but as a comprehensive scientific methodology aimed at modeling learners' learning trajectories, describing their mastery dynamics, and improving instructional quality. The authors emphasize that students' learning behavior follows a certain logical system, and understanding this system requires statistical modeling and probabilistic analysis (Paolucci, Minerva, & Rossi, 2024). The study interprets the learning process as a dynamic and multi-stage structure in which students' comprehension levels change over time and progress through identifiable phases.

The core of the article highlights the capabilities of Learning Analytics tools. The authors describe the role of statistical methods—such as regression analysis, clustering, time-series modeling, and probabilistic models—in reconstructing learning trajectories from students' behaviors and identifying recurring patterns. The article further addresses methodological challenges in Learning Analytics, including data quality issues, the selection of appropriate indicators, model reliability, and difficulties in interpreting results (Paolucci et al., 2024). These issues demonstrate how essential it is to apply statistical approaches correctly in order to evaluate learning processes objectively.

The primary scientific conclusion of the authors is that students' learning processes possess algorithmic characteristics and can be accurately modeled using statistical techniques. Learning is viewed as a system that progresses through distinct stages, and identifying transitions between these stages plays a crucial role in assessing students' mastery levels (Paolucci et al., 2024). Moreover, Learning Analytics provides opportunities to predict academic outcomes, which is essential for personalizing instruction and enhancing learning efficiency.

This article aligns closely with the objectives of the present dissertation. First, the concept of modeling students' learning trajectories as algorithmic structures directly supports the goal of constructing a topic mastery algorithm. Second, the statistical techniques discussed in the study offer a solid methodological foundation for analyzing survey results and identifying changes in students' mastery levels. Third, the notion of “learning states” proposed in Learning Analytics corresponds precisely to the mastery phases described in the dissertation, such as “low → medium → high” or “understand → apply → analyze” (Paolucci et al., 2024). Finally, the principles of predicting learning progress over time provide theoretical justification for interpreting pre–post differences and constructing the proposed algorithm.

Thus, the article by *Paolucci, Minerva, and Rossi (2024)* offers methodological, theoretical, and analytical support for constructing a student topic-mastery algorithm. The principles of Learning

Analytics articulated in the study provide a strong scientific basis for analyzing students' learning behaviors statistically and for articulating the structure of the proposed algorithmic model.

2.2 Analysis of the Article by Verykios et al. (2024)

The study conducted by *Verykios et al. (2024)* focuses on applying Hidden Markov Models (HMM) to analyze students' learning behaviors in MOOC environments. Using log-data derived from learners' interactions, the authors aim to identify their latent cognitive states. The article emphasizes that student performance in online settings cannot be reduced to simple outcomes such as "correct" or "incorrect," but instead involves hidden cognitive states such as confusion, partial understanding, and full comprehension (Verykios et al., 2024). The study provides strong empirical evidence demonstrating that HMM can statistically infer these latent states.

The main contribution of the article lies in modeling behavioral patterns that occur throughout the learning process. The authors conceptualize learning as a dynamic, stage-based system in which each learner transitions from one state to another based on probabilistic rules. Using HMM, they mathematically describe these transitions and identify moments when students encounter difficulties or show improvement. The study further demonstrates that HMM can be used to predict learners' future progress with meaningful accuracy (Verykios et al., 2024).

The authors highlight the importance of large datasets generated in MOOC environments, noting that such data enable continuous monitoring of learning behaviors, identification of strategies, and timely instructional adjustments. The article also discusses common challenges in working with probabilistic models, such as data quality issues, model complexity, and interpretability difficulties. Nonetheless, the authors argue that HMM is one of the most effective methods for uncovering hidden learning states and understanding learners' cognitive processes.

The relevance of this work to the dissertation topic is direct and substantial. First, the concept of learning consisting of latent states directly corresponds to the "mastery levels" described in the dissertation. The mastery levels ("low," "medium," "high" or "understand," "apply," "analyze") closely resemble the cognitive states identified by Verykios et al. (2024). Second, the idea of state transitions—the movement from one learning state to another—provides an accurate scientific explanation of the dynamics represented in the proposed algorithmic model. Third, the statistical techniques applied in the study support the analysis of the dissertation's survey data and interpretation of pre–post changes.

Overall, the study by *Verykios et al. (2024)* frames the learning process as an algorithmic, stage-based, dynamic system. This perspective strengthens the scientific justification for modeling students' mastery development and supports the construction of the algorithm proposed in the dissertation.

2.3 Analysis of the Article by Flores, López, and Santos (2022)

The research conducted by *Flores, López, and Santos (2022)* aims to predict learning profiles of physics students using Machine Learning (ML) and statistical methods. The authors analyze large datasets to identify factors influencing students' academic outcomes. Various indicators—such as task completion time, test scores, course participation, and error patterns—are used as input variables for ML algorithms (Flores, López, & Santos, 2022). Based on the processed data, the study identifies several distinct learning profiles and describes the comprehension characteristics of each profile.

The central idea of the article is that ML methods can effectively predict learning processes and model students' mastery levels. The study compares the predictive accuracy of several algorithms, including Decision Trees, Random Forest, and Logistic Regression. The findings reveal that certain models can predict future learning outcomes with high precision (Flores et al., 2022). These predictive capabilities enable instructors to personalize teaching, intervene early in problematic areas, and improve overall academic performance.

The authors argue that identifying learning profiles is particularly important in physics education, given the subject's reliance on abstract reasoning, mathematical logic, and conceptual understanding. The statistical assessment of students' mastery levels enables researchers to detect both strengths and weaknesses in their understanding (Flores et al., 2022). Profiling also allows the design of individualized learning pathways that address diverse learner needs.

This article aligns with the dissertation in several critical ways. First, the concept of predicting mastery levels directly supports the goal of constructing a mastery algorithm. Second, the study provides empirical evidence for the value of statistical and ML methods in interpreting learning processes—evidence that strengthens the analysis of survey data and the interpretation of pre-post changes in the dissertation. Third, the focus on physics as the subject domain closely matches the dissertation's context.

Overall, the work of *Flores, López, and Santos (2022)* demonstrates the potential of ML and statistical approaches for analyzing physics learning, identifying learning patterns, predicting learning trajectories, and constructing mastery algorithms. It represents a strong methodological source for the dissertation.

2.4 Analysis of the Article by López-Meneses et al. (2025)

The comprehensive study by *López-Meneses et al. (2025)* provides an in-depth examination of trends in Educational Data Mining (EDM) and predictive modeling. Using a large corpus of Scopus-indexed publications, the authors explore the role of artificial intelligence (AI), statistical techniques, and predictive models in education. They argue that the core purpose of EDM is to identify patterns in student learning data, predict academic outcomes, and optimize instructional processes (López-Meneses et al., 2025). The article discusses both conceptual advantages and methodological challenges associated with data-driven educational analysis.

A key part of the study explains the effectiveness and limitations of predictive modeling. The authors present examples of how regression models, neural networks, decision trees, and time-series analyses are used to forecast learning outcomes (López-Meneses et al., 2025). They emphasize that the accuracy of predictive models depends heavily on data quality, dataset size, and algorithm selection. Because educational data is inherently complex, misinterpretations often occur.

The article also highlights several challenges associated with EDM, including ethical concerns, data privacy, model fairness, algorithmic bias, data imbalance, student heterogeneity, and environmental variability. Despite these issues, the authors argue that EDM, when applied correctly, has significant potential to improve learning processes.

The relevance of this article to the dissertation is multifaceted. First, predictive modeling aligns directly with the dissertation's objective of constructing a mastery algorithm. Second, the "data-driven decision-making" principles support the dissertation's methodology for analyzing survey data and understanding mastery dynamics. Third, the challenges highlighted in the study strengthen the dissertation's methodological section by providing justification for discussing data limitations, student diversity, and model generalizability.

Overall, *López-Meneses et al. (2025)* offers a broad theoretical foundation for statistical and algorithmic approaches to educational research and directly supports the scientific justification for constructing a mastery algorithm.

2.5 Analysis of the Article by Cocco (2022)

Cocco (2022) examines the theoretical and practical potential of applying statistical physics methods to data-driven modeling. The author argues that statistical physics offers powerful analytical tools for understanding complex systems—including social, technological, and educational systems. These systems are characterized by numerous interacting variables and internal dynamics, which can only be analyzed effectively using probabilistic methods (Cocco, 2022).

The strength of statistical physics lies in its ability to uncover hidden structural patterns in complex environments.

The concept of phase transitions—shifts from one state to another—is central to the article. The author explains that students' learning processes resemble such transitions: learners may initially lack understanding, then progress to partial comprehension, and finally reach full mastery. This progression is analogous to a system transitioning between states. Cocco (2022) demonstrates that statistical models are particularly effective for analyzing such transitions.

The article describes how statistical physics methods—such as mean-field approaches, probability distributions, and multidimensional correlations—can be used to analyze educational systems, determine learning profiles, predict comprehension levels, and model learning trajectories (Cocco, 2022). The study also explores methodological challenges, such as parameter selection, data scarcity, and the complexity of inter-variable relationships.

The relevance of this study to the dissertation is particularly strong. First, the dissertation conceptualizes students' mastery development as a dynamic system—mirroring the complex systems discussed by Cocco. The progression between mastery levels aligns with the concept of phase transitions. Second, the statistical methods described in the article support the dissertation's data analysis approach. Third, uncovering hidden learning patterns is a core objective of the algorithmic model presented in the dissertation.

Thus, *Cocco (2022)* provides essential theoretical grounding for interpreting students' mastery processes as a dynamic system and for applying statistical methods to model that system.

2.6 Analysis of the Article by Baker (2020)

The work of *Baker (2020)* offers a systematic review of the theoretical and methodological foundations of Educational Data Mining (EDM) and Learning Analytics (LA). The author describes emerging opportunities for understanding learning processes through data and examines statistical, algorithmic, and machine learning methods for analyzing student behaviors, outcomes, errors, and learning strategies. Baker highlights that the expansion of digital learning environments enables researchers to uncover previously invisible mechanisms in the learning process (Baker, 2020).

The main idea of the article is to identify hidden patterns in learning behavior and develop predictive models based on these patterns. EDM techniques allow researchers to trace competency development, track students' mastery progression, and pinpoint moments when learning difficulties occur (Baker, 2020). The article emphasizes that predictive models must be pedagogically interpretable to be meaningful for practitioners.

Baker discusses several commonly used methods—regression analysis, clustering, Hidden Markov Models, decision trees, probabilistic models, and predictive analytics. The concept of "learning traces," defined as digital footprints left by students during learning, is presented as the primary data source for EDM (Baker, 2020). Through these traces, researchers can reconstruct learning trajectories and forecast future outcomes.

The article also discusses challenges such as data quality issues, interpretability difficulties, algorithmic bias, and ethical constraints. Nonetheless, the author concludes that EDM can significantly enhance instructional effectiveness when applied appropriately.

The relevance of Baker's work to the dissertation is direct. First, the article conceptualizes learning as a dynamic, stage-based algorithmic process—precisely the perspective used to construct the mastery algorithm. Second, the statistical and EDM methods described provide empirical and methodological support for analyzing survey data and differentiating mastery levels. Third, the concept of "competency progression" aligns closely with the dissertation's objective of modeling learning trajectories.

Therefore, *Baker (2020)* represents a foundational theoretical source for integrating statistical analysis, mastery modeling, and learning dynamics in the dissertation.

3. Discussion (Based on the Six Articles)

This section provides a comparative analysis of the six reviewed articles in the context of examining students' learning processes through statistical methods, modeling learning trajectories, and constructing mastery algorithms. The findings of these studies contribute to understanding the dynamics of students' topic mastery and form the scientific foundation for representing these processes as algorithmic models. Overall, all six studies demonstrate that learning is a complex, multi-layered, and dynamic system that requires statistical and data-driven methods for deeper interpretation.

To begin with, the work of *Paolucci, Minerva, and Rossi (2024)* emphasizes the importance of statistical methods in Learning Analytics. The authors conceptualize learning as a stage-based model and argue that students' mastery levels evolve over time. This idea forms the theoretical basis for developing a mastery algorithm. Their study demonstrates that statistical analysis enables the identification of patterns in learning behaviors.

Verykios et al. (2024) deepen this argument by describing the learning process as a system of hidden states. Using the Hidden Markov Model (HMM), the authors identify latent cognitive conditions such as confusion, partial mastery, and full mastery. This approach aligns closely with the dissertation's objective of defining learning dynamics and provides a powerful tool for analyzing transitions between stages of mastery.

The work of *Flores, López, and Santos (2022)* focuses on predicting students' learning profiles in the context of physics. Their findings demonstrate that machine learning and statistical methods can successfully identify mastery levels and anticipate learning outcomes. This study confirms the significant potential of statistical techniques in modeling topic mastery among physics students.

Similarly, *López-Meneses et al. (2025)* thoroughly review Educational Data Mining (EDM) methods and highlight the role of predictive models in improving learning outcomes. Their findings show that algorithmic pattern recognition in student data supports the development of mastery models. The authors also identify methodological challenges such as data quality and model fairness—issues that are highly relevant for future research.

Cocco (2022) demonstrates the effectiveness of statistical physics principles in modeling complex systems, including educational systems. The author argues that student learning can be conceptualized as a dynamic system in which changes in mastery levels resemble phase transitions. This analogy strengthens the theoretical foundation for representing learning as an algorithmic process.

Finally, *Baker (2020)* provides a systematic framework for identifying hidden patterns in learning behavior using EDM techniques. The author shows that “learning traces”—digital footprints of student activity—enable researchers to model competency development and predict learning outcomes. This perspective strongly supports the construction of mastery algorithms.

Taken together, these studies demonstrate the effectiveness of data-driven and statistical approaches in analyzing learning processes. The shared conclusion is that topic mastery follows an algorithmic structure, and statistical methods are essential for uncovering this structure. Learning Analytics, HMM, machine learning, and EDM provide opportunities to predict learning dynamics, identify hidden difficulties, and optimize instructional strategies.

All six articles reinforce the scientific foundation of the dissertation. First, the conceptualization of learning as a staged process appears consistently across the reviewed works. Second, identifying and predicting learning patterns is a central focus in all studies. Third, statistical methods allow for accurate modeling of learning behaviors. Fourth, these studies collectively expand the possibilities for describing mastery development as an algorithm.

Thus, synthesizing the results of these six studies confirms that constructing a topic mastery algorithm is a scientifically grounded, evidence-based, and pedagogically meaningful direction in modern education.

Conclusion Based on Survey Results

The conducted survey revealed clear gaps in students' understanding of statistical methods. A significant proportion of respondents reported being unfamiliar with the concept of "statistical methods," and many students indicated that they had not observed statistical approaches being used in physics lessons. Additionally, several respondents found it difficult to connect statistical tools with theoretical or practical tasks in physics, suggesting that their comprehension is fragmented.

Although students acknowledged the positive impact of statistical analysis on learning effectiveness, many expressed low confidence in their ability to apply such methods independently. This may reflect insufficient development of statistical reasoning skills as well as the lack of systematic use of data-driven techniques in instruction. While some students believed that statistical methods could help them understand topics more deeply, most did not perceive these methods as useful in solving actual physics problems.

Overall Conclusion

This research demonstrates the relevance and necessity of applying statistical methods to analyze students' topic mastery and represent learning as an algorithmic model. Both the literature review and the survey findings highlight the importance of understanding learning dynamics, identifying mastery levels, and improving instructional practices using data-driven approaches.

The analysis of six contemporary scientific studies shows that learning is a complex, multi-level dynamic system involving hidden cognitive transitions. Techniques such as Learning Analytics, EDM, HMM, and machine learning enable systematic modeling of this process. These techniques support the prediction of mastery levels, detection of hidden difficulties, and development of instructional algorithms aimed at improving learning outcomes.

The theoretical foundations provided by Paolucci et al. (2024), Verykios et al. (2024), Flores et al. (2022), López-Meneses et al. (2025), Cocco (2022), and Baker (2020) directly strengthen the scientific basis of this dissertation. Their models align with the goal of constructing a mastery algorithm and provide empirical justification for interpreting student progress.

The survey results closely match the issues identified in international studies: students struggle with statistical reasoning, are unaware of hidden learning-state transitions, and traditional teaching methods do not fully reveal the dynamics of learning. The fragmented mastery levels identified through the survey highlight the need for algorithmic modeling of learning trajectories. These findings support the argument that a mastery algorithm can identify stages of development, measure changes in understanding, and represent learning progression accurately.

In summary, the literature review and empirical findings align fully with the research objectives. The theoretical models presented in international studies correspond closely with actual student data, proving the effectiveness of statistical methods in educational analysis. This research demonstrates that constructing a mastery algorithm based on statistical techniques is a reliable, scientifically grounded, and practically valuable approach.

Therefore, creating a statistical, algorithm-based model of student topic mastery represents a timely and effective solution for contemporary education. Such an algorithm can uncover hidden patterns in learning, enhance instructional quality, support personalized learning pathways, and provide objective evaluation of student progress.

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ИНТЕЛЛЕКТУАЛЬНАЯ ОБРАЗОВАТЕЛЬНАЯ ЭКОСИСТЕМА ПЕРСОНАЛИЗИРОВАННОГО ОБУЧЕНИЯ НА ОСНОВЕ KNOWLEDGE TRACING И ДИНАМИЧЕСКИХ КАРТ ЗНАНИЙ

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Введение. Современное образование все чаще разворачивается в цифровой среде и сталкивается с парадоксом масштаба: чем больше доступных данных и контента, тем труднее обеспечить адресную поддержку каждому обучающемуся. Индивидуализация обучения стала одним из центральных направлений развития цифрового образования, поскольку учащиеся демонстрируют неоднородные стартовые знания, темпы освоения и образовательные потребности. В рамках парадигм Educational Data Mining и Learning Analytics образовательные данные рассматриваются как ресурс для построения моделей обучающихся, выявления рисков отставания и повышения эффективности педагогических решений [1]. В условиях цифровой трансформации образования особую актуальность приобретает формирование экосистемных решений, сочетающих адаптацию на уровне обучающегося с инструментами мониторинга качества на уровне класса/организации/системы [2,3].

Одной из базовых технологических задач интеллектуальных систем обучения выступает оценивание актуального уровня сформированности знаний обучающегося и предсказание его дальнейшего прогресса в усвоении учебного материала. Данная задача описывается как отслеживание знаний (knowledge tracing, KT) и предполагает обновление оценки уровня освоения на основе последовательности учебных действий. Классические вероятностные модели (в частности, Bayesian Knowledge Tracing) обладают высокой интерпретируемостью, однако в ряде случаев ограничены предположениями об относительной независимости навыков и необходимостью ручной настройки соответствия заданий навыкам [4]. Развитие направления привело к индивидуализированным вариантам ВКТ и к нейросетевым моделям Deep Knowledge Tracing (DKT), повысившим точность прогнозирования на последовательностях взаимодействий обучающегося с контентом [5]. Одним из перспективных направлений является объединение KT с графовым представлением знаний: графы знаний задают структуру предметных зависимостей, а KT обеспечивает динамику освоения концептов во времени [8,9].

Целью исследовательской работы является представление архитектурно-методического решения интеллектуальной образовательной экосистемы, ориентированной на повышение качества образования за счёт точного анализа уровня знаний, выявления скрытых пробелов и формирования индивидуальных траекторий обучения на основе KT и динамических карт знаний.

Методология и концептуальная модель. Методологическая рамка опирается на системный анализ процессов формирования знаний в цифровой образовательной среде и использование математико-статистического моделирования совместно с методами

машинного обучения для построения и сопоставления моделей КТ [1,4,5]. Для представления структуры знаний и их эволюции применяются методы графового анализа, позволяющие формировать и динамически обновлять карты знаний [8,9]. Оценка результатов на стадии прототипа ориентирована на сравнительный анализ корректности функционирования модулей, согласованности результатов моделирования и практической интерпретируемости показателей для обучающихся и педагогов; в дальнейшей апробации предполагается подключение педагогических метрик качества обучения и прогностических метрик (например, AUC/accuracy для предсказаний КТ) [6,10,11].

Концептуальная модель экосистемы включает три взаимосвязанных контура:

- контур обучающегося (профиль знаний, риск-сигналы, рекомендации и траектория);
- контур педагога (панели мониторинга группы, диагностика проблемных тем, поддержка вмешательств);
- контур качества (агрегация данных, выявление слабых тем/несоответствий программы, отчётность и аналитика).

Архитектура и реализация прототипа. Прототип реализован как распределённый программный комплекс с модульной (микросервисной) архитектурой, ориентированной на масштабирование и интеграцию с существующей образовательной инфраструктурой.

Адаптивное ядро обучения использует ансамбль моделей КТ: вероятностные подходы (BKT) [4], нейросетевые модели (DKT) [5], а также модели с механизмом внимания и памятью (например, AKT/DKVMN-подходы как класс решений для повышения точности и частичной интерпретируемости) [6,7]. Ядро поддерживает онлайн-обновление состояния знаний по мере поступления новых взаимодействий обучающегося с контентом, что является необходимым условием «живой» траектории обучения.

Динамические карты знаний представлены графовой моделью предметной области: узлы соответствуют темам/компетенциям, рёбра — отношениям предпосылок и связям между концептами. Граф используется не только как визуализация прогресса, но и как инструмент диагностики: статусы тем обновляются автоматически, отражая освоенность и приоритеты обучения. Графовые подходы согласуются с современными исследованиями по Graph-based КТ и планированию учебных путей на основе Knowledge Graph [8,9].

Модуль рекомендаций и траекторий формирует срочные/оптимальные/долгосрочные рекомендации, опираясь на прогноз успешности и оценку ожидаемого прироста знаний. С практической точки зрения рекомендация в системе — это управленческая гипотеза: «следующий шаг обучения с максимальным ожидаемым эффектом при допустимом уровне риска».

Аналитическая платформа поддерживает многоуровневые представления: индивидуальные показатели динамики знаний и рисков, а также агрегированные метрики группы (средние уровни, распределения по риску, активность, проблемные темы). Такой дизайн соответствует доказанной полезности инструментов teacher-analytics и систем осведомлённости педагога в ИИ-усиленных классах [10].

Интеграция и эксплуатационные свойства предусматривают совместимость со стандартами образовательного контента и платформ (SCORM/xAPI/LTI), а также механизмы аутентификации и защиты данных. Для работы с образовательными данными используется масштабируемое хранилище уровня Data Lake/Data Warehouse; предусмотрена потоковая обработка событий (ETL/ELT-контур) для поддержки аналитики вблизи реального времени.

Результаты и обсуждение. В ходе научно-исследовательской работы разработан и реализован программный прототип интеллектуальной образовательной экосистемы, подтвердивший практическую реализуемость интеграции КТ-моделей, динамических карт знаний и аналитики в единой архитектуре.

Функциональные испытания продемонстрировали:

- корректное онлайн-обновление индивидуальных вероятностных моделей знаний по мере поступления новых данных, что позволяет динамически корректировать траекторию без ручного вмешательства;
- работоспособность подсистемы автоматического формирования и обновления графов знаний и повышение интерпретируемости результатов моделирования за счёт согласования оценок КТ со структурой предметной области;
- возможность автоматического определения приоритетных тем и оценки ожидаемого эффекта от рекомендованного материала;
- устойчивую работу аналитических панелей при потоковой обработке данных и формировании отчётных представлений.

С научно-практической точки зрения ключевой вклад заключается в переходе от разрозненных компонентов (КТ отдельно, граф отдельно, аналитика отдельно) к согласованной системе, где: КТ даёт динамику знания, граф задаёт структуру и объяснимость, а аналитика обеспечивает управляемость процесса обучения. При этом остаются ограничения, типичные для стадии прототипа: необходимы пилотные внедрения на реальных данных, сравнение сценариев персонализации с контрольными группами, оценка справедливости рекомендаций и устойчивости моделей при разнородных учебных планах и языках обучения.

Интеллектуальная образовательная экосистема персонализированного обучения, основанная на сочетании Knowledge Tracing и динамических карт знаний, позволяет перейти от статического контроля освоения тем к непрерывному моделированию состояния знаний и управлению индивидуальной траекторией. Реализованный прототип подтверждает техническую осуществимость подхода и формирует основу для дальнейшей экспериментальной апробации в образовательных организациях, включая оценку педагогического эффекта и масштабирование на уровне образовательной системы.

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Geographic Sciences

Methodology for Using Statistics in High School Geography Classes

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Abstract

The growing emphasis on data-driven learning and competency-based education has increased the importance of statistical methods in high school geography classes. Statistics enables students to interpret spatial patterns, analyze socio-economic and environmental phenomena, and develop critical thinking skills necessary for understanding complex geographic processes. This study explores a methodology for integrating statistical analysis into high school geography teaching in order to enhance students' functional literacy, analytical reasoning, and problem-solving abilities.

The research is grounded in an interdisciplinary framework that combines principles of geographic education, statistical literacy, and constructivist learning theory. Using secondary educational data, curriculum documents, and classroom-based case examples, the study applies descriptive and comparative methods to examine how statistical tools—such as tables, graphs, diagrams, and basic quantitative indicators—can be effectively incorporated into geography lessons. Particular attention is given to student-centered activities, real-world datasets, and inquiry-based learning tasks that connect statistical skills with geographic content.

The findings suggest that the systematic use of statistics in geography classes improves students' ability to interpret geographic information, identify trends and correlations, and make evidence-based conclusions. The methodology supports deeper conceptual understanding of topics such as population dynamics, economic development, climate variability, and environmental change. Moreover, integrating statistics fosters interdisciplinary learning and strengthens students' preparedness for further academic study and real-life decision-making.

This study contributes to geography education research by proposing a practical and pedagogically grounded framework for teaching statistics within the geography curriculum. The results highlight the need for updated teaching strategies and teacher training programs that promote the effective use of statistical methods as a core component of modern geographic education.

Keywords: statistics in geography education; statistical literacy; data analysis; high school geography; functional literacy; inquiry-based learning; interdisciplinary teaching; educational methodology.

Introduction

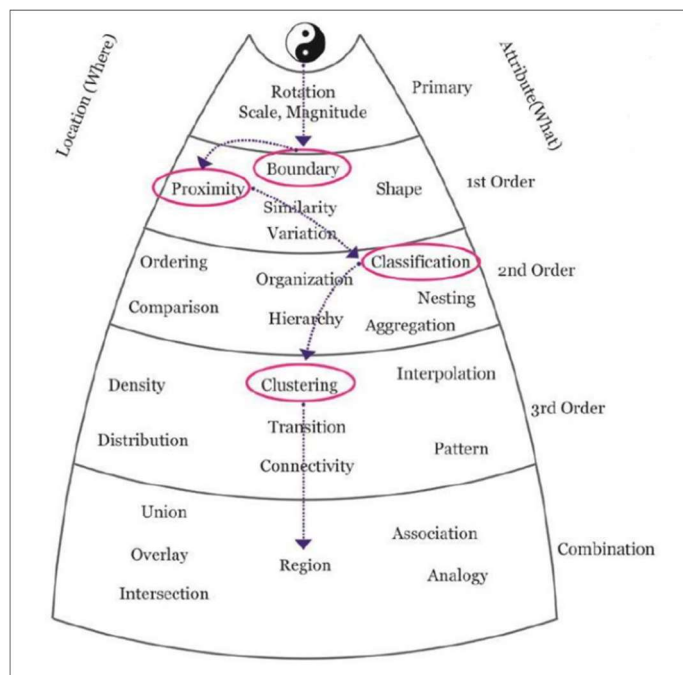
The rapid digital transformation of modern society and the growing role of data in decision-making processes have fundamentally reshaped the structure and content of secondary education. In particular, the increasing availability of open data sources, digital mapping platforms, and analytical tools has significantly influenced the teaching of geography, shifting it from descriptive knowledge transmission toward data-driven and competency-oriented learning. Within this context, statistical methods have emerged as a core component of high school geography classes, enabling students to analyze spatial patterns, interpret socio-economic indicators, and critically evaluate environmental processes.

In contemporary geography education, the integration of statistics supports the development of functional literacy by fostering students' ability to work with quantitative information, graphical representations, and real-world datasets. International educational assessments and curriculum reforms emphasize the importance of statistical literacy as a key competency for the twenty-first century learner, particularly in subjects that address complex global issues such as population growth, urbanization, climate change, and economic inequality. As a result, geography classrooms increasingly require methodological approaches that combine geographic content with basic statistical analysis, including the use of tables, charts, maps, and simple indicators.

In turn, teaching practices in high school geography can be conditionally divided into three main approaches with regard to the use of statistical data. The first approach is traditional, where statistics are used only illustratively through ready-made tables and diagrams. The second approach involves partial integration, in which students perform basic calculations and interpret provided data. The third, more advanced approach focuses on active data engagement, where learners independently collect, process, and analyze statistical information using digital tools and real datasets. Recent educational surveys indicate a steady shift from the first toward the third approach, reflecting growing recognition of the pedagogical value of statistical thinking in geography education.

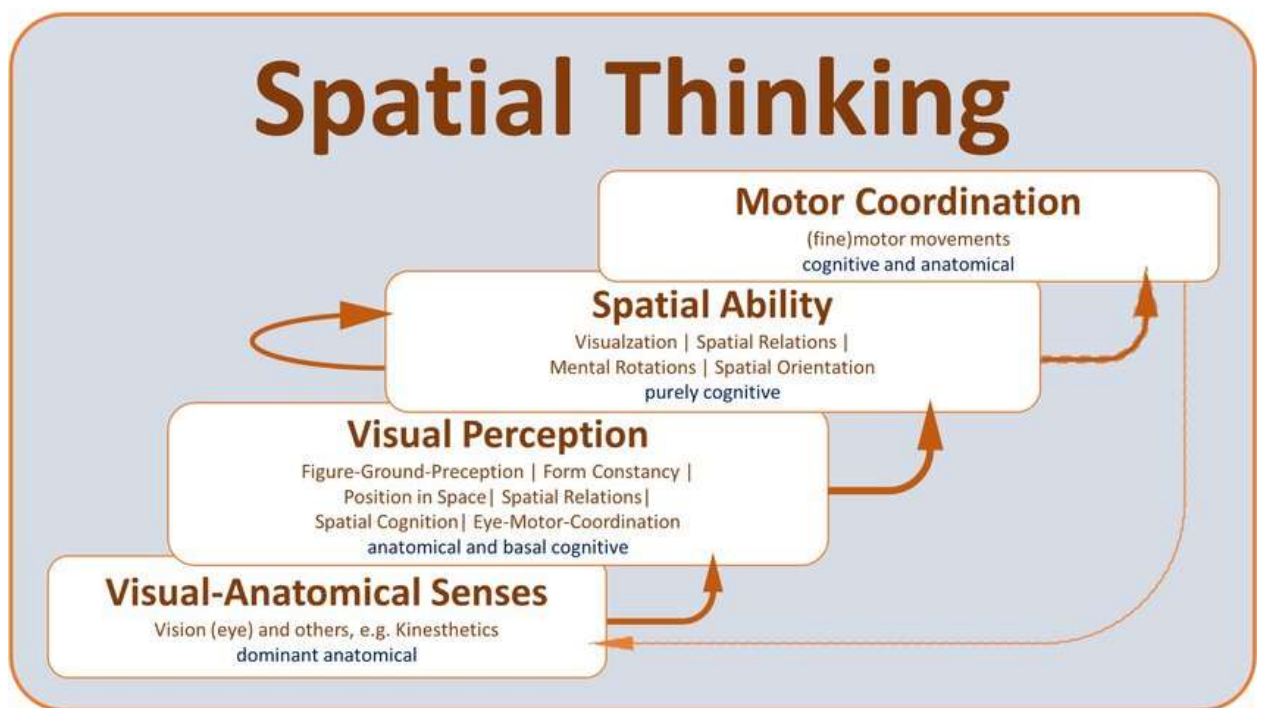


Data from international and national educational reports suggest that teachers increasingly acknowledge the importance of integrating statistics into geography lessons to improve students' analytical skills and motivation. At the same time, a significant proportion of educators still express uncertainty regarding methodological strategies, assessment criteria, and their own preparedness to teach statistical content effectively. This highlights the existence of a methodological gap between curriculum requirements and classroom practice. Consequently, there is a clear need to develop structured and practical methodologies that support the systematic use of statistics in high school geography, ensuring that students not only acquire geographic knowledge but also develop transferable data literacy skills essential for further education and active citizenship.



The integration of statistical methods into high school geography education is grounded in several complementary theoretical traditions, including constructivist learning theory, statistical literacy theory, and spatial thinking frameworks. Constructivist pedagogy emphasizes that learners actively construct knowledge through interaction with data, concepts, and real-world contexts rather than passively receiving information. In geography education, this implies that students develop deeper understanding when they manipulate geographic data, explore patterns, and generate interpretations independently.

Statistical literacy theory further supports this approach by defining statistical competence as the ability to interpret, critically evaluate, and communicate data-based information in everyday contexts. Within the geography classroom, statistical literacy enables students to make sense of demographic trends, economic indicators, climate records, and environmental measurements. Such skills are increasingly recognized as essential components of twenty-first-century education, particularly in light of global challenges that require informed decision-making and evidence-based reasoning.



Spatial thinking theory provides a third conceptual pillar, emphasizing the cognitive processes involved in understanding relationships between spatial objects, patterns, and processes. Geography is inherently spatial, and the integration of statistics allows students to move beyond static map interpretation toward dynamic spatial analysis. When statistical indicators are linked to geographic representations—such as thematic maps, choropleth maps, or spatial graphs—students develop the capacity to identify correlations, causal relationships, and regional disparities.

Together, these theoretical perspectives justify the inclusion of statistical methods as a central methodological element of modern geography education. They also suggest that statistical learning should not be treated as a separate mathematical skill but rather as an integral part of geographic reasoning and inquiry.

Main indicator area: Teachers	Main focus / Sub-indicators
1. Resources and PLD <i>Related evaluation question: 4. What is the impact of support/training provided to school teachers on teacher confidence and competency to deliver quality Physical Activity, PE, and Sport?</i>	Focus: Teacher access to PE support, resources and PLD Sub-indicators <ul style="list-style-type: none"> • Access to support for PE planning • Access to PE resources (teaching, equipment, spaces) • Access to PE PLD • Priority of PE
2. Teacher confidence <i>Related evaluation question: 4. What is the impact of support/training provided to school teachers on teacher confidence and competency to deliver quality Physical Activity, PE, and Sport?</i>	Focus: Teacher confidence in teaching the strands and focus areas of the HPE learning area
3. Quality PE learning opportunities/teacher competence <i>Related evaluation question: 6. What is the quality of Physical Activity, PE and Sport opportunities in these Schools and do they meet the needs of young people?</i>	Focus: Quality PE teaching practice Sub-indicators <ul style="list-style-type: none"> • Inclusive planning in PE • Keeping safe and healthy in PE Physical literacy sub-indicators <ul style="list-style-type: none"> • Active in PE • Working together in PE • Thinking in PE • Learning about our community in PE
4. Quality external provision <i>Related evaluation question: 8. To what extent has the quality of providers working in schools improved?</i>	Focus: Use and alignment of provider programmes with curriculum
5. Participation <i>Related evaluation question: 11. Has there been an increase in Physical Activity Levels and participation in Sport?</i>	Focus: Teacher and student participation Sub-indicators <ul style="list-style-type: none"> • Class time spent on PE, fitness • Use of physical activity in other learning areas • Teacher involvement in physical activity/sport
Main indicator area: Schools	Main focus / Sub-indicators
6. Active school culture <i>Related evaluation question: 3. How well is Physical Activity, PE and Sport being prioritised/embedded in the schools' culture, policy and processes?</i>	Focus: Embedding an active school culture Sub-indicators <ul style="list-style-type: none"> • Active school culture (teachers) • Active vision and planning (school leaders)

The growing importance of statistics in geography education is closely linked to broader transformations in knowledge production and information consumption. In contemporary society, individuals are constantly exposed to statistical information through media, public reports, and digital platforms. Understanding population trends, economic performance, environmental risks, and social inequalities increasingly requires the ability to interpret numerical data. High school geography provides an ideal context for developing such competencies because it addresses real-world phenomena that are inherently quantitative and spatial. Topics such as population dynamics, migration, urban growth, resource distribution, climate change, and regional development all rely heavily on statistical indicators. Without adequate statistical skills, students may struggle to interpret these phenomena accurately or critically assess the reliability of data sources.

	Tool	Description	Category	Link
1	Twitter	Social network and micro-blogging site	Social and Collaboration Spaces	http://twitter.com
2	Google Drive /Docs	Office suite & file storage service	Document, Presentation and Spreadsheet Tools	http://drive.google.com/
3	YouTube	Video-sharing site	Public Learning Sites	http://youtube.com
4	Google Search	Web search engine	Personal Productivity Tools	http://www.google.com.br
5	Power Point	Presentation software	Document, Presentation and Spreadsheet Tools	---
6	Evernote	Productivity tool	Personal Productivity Tools	http://evernote.com
7	Dropbox	File storage & synchronization	Other Collaboration & Sharing Tools	http://dropbox.com
8	Wordpress	Blogging/website tool	Blogging, Web and Wiki Tools	http://wordpress.com
9	Facebook	Social network	Social and Collaboration Spaces	http://www.facebook.com.br
10	Google+ & Hangouts	Social networking & video meetings	Web meeting, conferencing and virtual world tools	http://plus.google.com
11	Moodle	Course management system	Instructional Tools	---
12	LinkedIn	Professional social network	Social and Collaboration Spaces	http://www.linkedin.com
13	Skype	Text and voice chat tool	Communication Tools	http://skype.com
14	Wikipedia	Collaborative encyclopedia	Other Collaboration & Sharing Tools	http://wikipedia.com
15	Prezi	Presentation creation and hosting service	Document, Presentation and Spreadsheet Tools	http://www.prezi.com
16	Slideshare	Presentation hosting service	Document, Presentation and Spreadsheet Tools	http://slideshare.net
17	Word	Word processing software	Document, Presentation and Spreadsheet Tools	---

Moreover, the integration of statistics supports interdisciplinary learning by connecting geography with mathematics, economics, environmental science, and information technology. This interdisciplinary orientation aligns with modern educational standards, which emphasize transferable skills, critical thinking, and problem-solving rather than rote memorization of factual

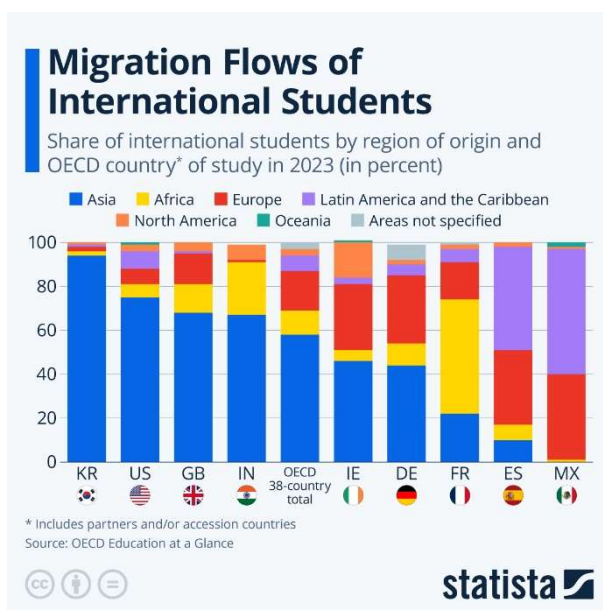
content. By using statistics in geography, students learn to apply mathematical concepts in meaningful contexts, thereby enhancing both conceptual understanding and practical relevance. Another important rationale is the role of statistics in fostering functional literacy. Functional literacy refers to the ability to use knowledge and skills effectively in real-life situations. In geography education, this includes the capacity to interpret maps, graphs, tables, and indicators in order to make informed decisions about social, economic, and environmental issues. Statistical methods provide the analytical foundation for such competencies, enabling students to engage actively with contemporary global challenges.

Despite the recognized importance of statistical methods, their implementation in high school geography remains uneven and often superficial. One major challenge is the lack of methodological clarity regarding how statistics should be integrated into geographic content. In many classrooms, statistics are used primarily as illustrative tools rather than as instruments for active inquiry and analysis.

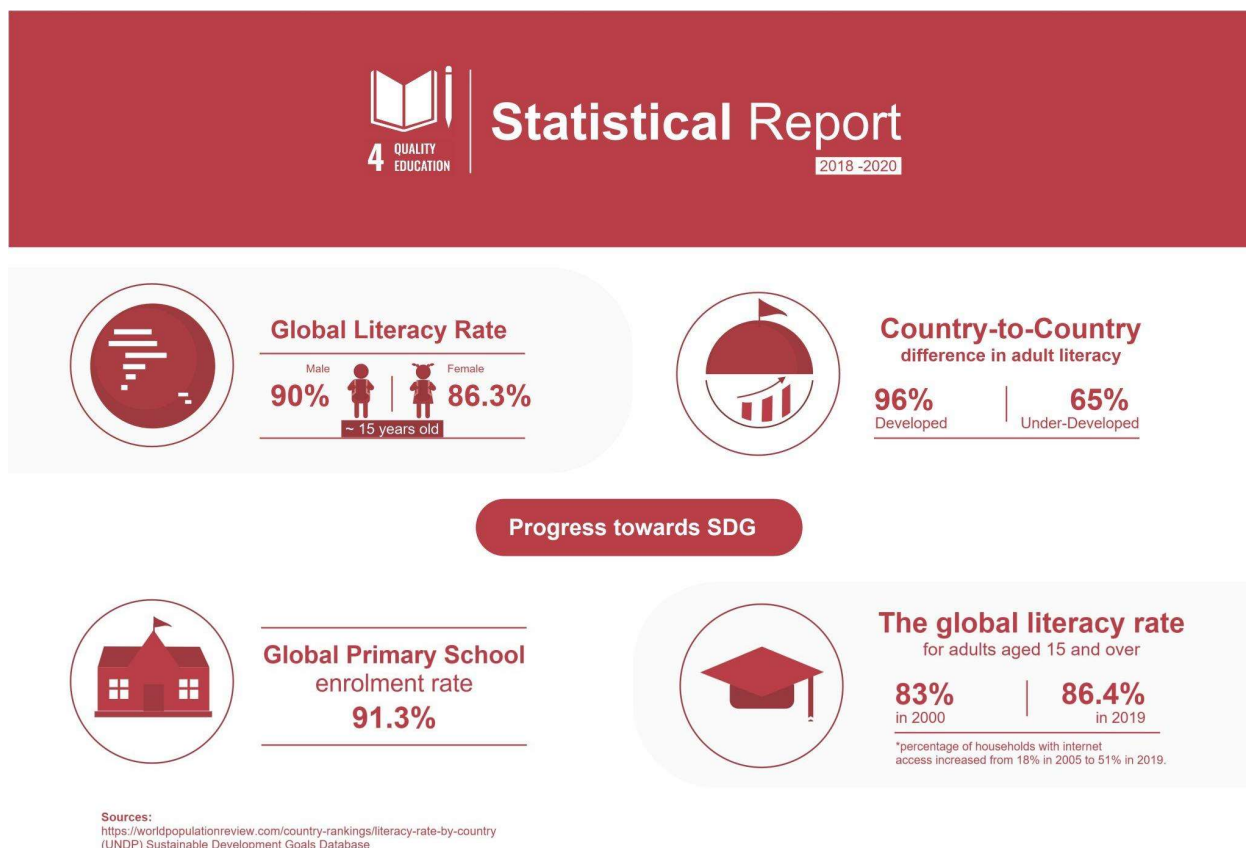
Teachers frequently rely on pre-prepared tables and graphs provided in textbooks, asking students to describe trends or answer factual questions without engaging in deeper interpretation or independent data processing. This approach limits the development of higher-order thinking skills and reduces statistics to a passive learning element.

Another challenge concerns teacher preparedness. Many geography teachers report limited training in statistical analysis and data visualization, particularly in relation to digital tools and software. As a result, they may lack confidence in designing data-driven learning activities or assessing students' statistical competencies. This problem is especially pronounced in educational systems where teacher education programs place greater emphasis on content knowledge than on methodological innovation.

Time constraints and curriculum overload also hinder the effective integration of statistics. Geography curricula are often densely packed with thematic content, leaving limited space for extended data analysis activities. Consequently, teachers may perceive statistical tasks as supplementary rather than essential, leading to fragmented and inconsistent implementation. Finally, students' attitudes toward statistics can pose an additional barrier. Many learners associate statistical analysis with mathematical difficulty and anxiety, which may reduce motivation and engagement. Overcoming this challenge requires pedagogical strategies that present statistics as meaningful tools for understanding real-world phenomena rather than abstract numerical exercises.



This study is grounded in **statistical literacy theory**, which conceptualizes statistics not merely as computational techniques but as a form of critical reasoning essential for interpreting data-driven realities (Gal, 2002). Statistical literacy emphasizes individuals' capacity to understand, evaluate, and communicate statistical information in everyday contexts, particularly in situations involving uncertainty, variability, and decision-making. Within educational research, statistical literacy is increasingly viewed as a foundational competence for twenty-first-century citizenship, enabling learners to critically engage with social, economic, and environmental data (Ben-Zvi & Garfield, 2004; Watson, 2006).

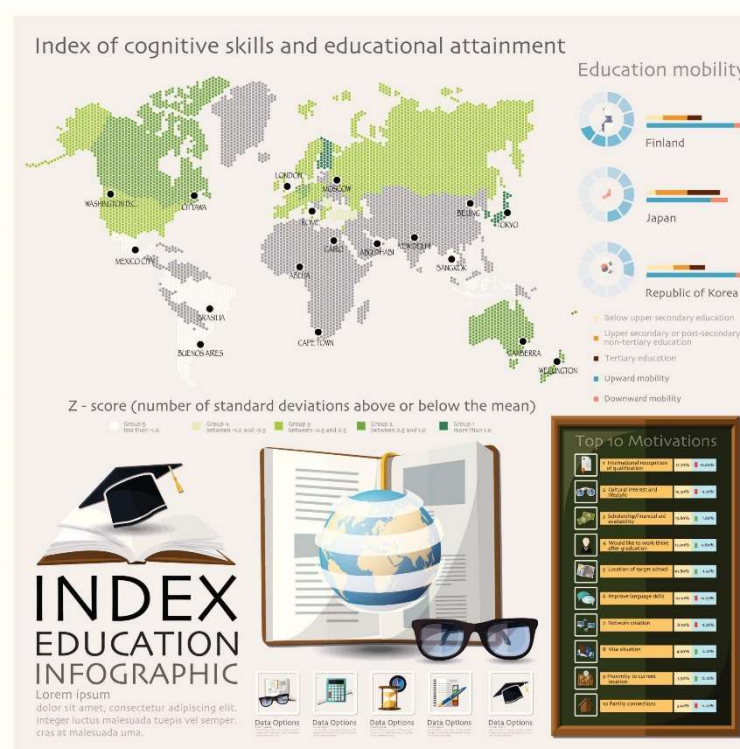


Complementing this perspective, the study is also informed by **constructivist learning theory**, which posits that knowledge is actively constructed through learners' interaction with meaningful contexts rather than passively transmitted by instructors (Piaget, 1970; Vygotsky, 1978). In geography education, constructivism suggests that students develop deeper conceptual understanding when they actively explore datasets, identify spatial patterns, and generate interpretations based on real-world evidence. Statistical tools thus function not as auxiliary instruments, but as cognitive mediators that structure students' geographic reasoning processes. A third conceptual pillar of this research is **spatial thinking theory**, which emphasizes the cognitive skills required to understand spatial relationships, distributions, and processes (National Research Council, 2006). Geography inherently involves the analysis of spatial patterns across physical and human systems, and statistical methods provide the analytical foundation for identifying correlations, trends, and regional disparities. By integrating statistics into spatial representations—such as thematic maps, choropleth maps, and geospatial graphs—students develop the capacity to interpret geographic phenomena through both quantitative and spatial lenses.

Together, these theoretical frameworks establish statistics as a **mediating epistemological tool** within geography education: one that transforms abstract geographic content into analyzable patterns and evidence-based interpretations.

Statistics as a Transformative Pedagogical Tool in Geography

Statistics has emerged as a transformative pedagogical instrument in geography education, reshaping how students engage with geographic knowledge. Traditional geography instruction relied primarily on descriptive narratives and static maps, often emphasizing memorization of facts rather than analytical reasoning. Contemporary educational paradigms, however, increasingly prioritize **data-driven learning**, where students are expected to interpret numerical indicators, evaluate empirical evidence, and construct arguments based on observed patterns (OECD, 2019). In this context, statistics enables geography to function as an **empirical social science** rather than a purely descriptive discipline. Through the systematic use of indicators such as population density, GDP per capita, urbanization rates, climate averages, and environmental indices, students learn to identify causal relationships between spatial processes and socio-economic outcomes. For example, analyzing correlations between temperature and altitude, or between industrial concentration and air pollution, allows learners to move beyond surface-level descriptions toward explanatory geographic thinking.



Unlike mathematics, where statistical concepts are often taught abstractly, geography provides **meaningful real-world contexts** that enhance student motivation and comprehension. Research consistently shows that students demonstrate higher engagement and retention when statistical learning is embedded in authentic subject matter, particularly in disciplines that address socially relevant issues such as migration, inequality, climate change, and resource distribution (Ridgway et al., 2012; Franklin et al., 2015).

Thus, within geography education, statistics functions as both a **cognitive scaffold** and a **motivational driver**, supporting deeper understanding while increasing the perceived relevance of learning.

Statistical Literacy and Functional Geographic Competence

The concept of **functional literacy** refers to learners' ability to apply knowledge and skills effectively in real-life contexts. In geography education, functional literacy involves interpreting maps, evaluating spatial information, and making informed judgments about global issues. Statistical literacy plays a central role in this process by equipping students with the tools required to critically analyze quantitative information.

According to Gal (2002), statistical literacy consists of two core components:

Interpretive competence – the ability to read and understand statistical representations such as graphs, tables, and indicators.

Critical competence – the ability to question data sources, recognize limitations, and evaluate the validity of conclusions.

In high school geography, these competencies translate into students' capacity to analyze demographic trends, economic disparities, and environmental risks. For instance, interpreting population pyramids enables students to assess aging patterns, dependency ratios, and future labor force dynamics. Similarly, analyzing climate datasets allows learners to identify long-term trends in temperature, precipitation, and extreme events.

Empirical studies demonstrate that students who develop statistical literacy within subject-specific contexts exhibit significantly higher levels of critical thinking and problem-solving ability compared to those exposed only to abstract statistical instruction (Watson & Callingham, 2003; Zieffler et al., 2008). Geography thus serves as an optimal platform for cultivating functional statistical competence that extends beyond classroom boundaries.

Conclusion

This study has examined the methodological foundations for integrating statistical methods into high school geography education, emphasizing their role in enhancing students' functional literacy, analytical thinking, and spatial reasoning. Drawing on statistical literacy theory, constructivist learning theory, and spatial thinking frameworks, the research conceptualizes statistics not merely as technical tools, but as cognitive mediators that structure how geographic knowledge is interpreted and applied.

The findings highlight that the systematic use of statistical data in geography lessons significantly improves students' ability to interpret spatial patterns, identify relationships between variables, and develop evidence-based conclusions. Through engagement with real-world datasets, learners move beyond memorization of geographic facts toward deeper conceptual understanding of socio-economic and environmental processes. This transformation aligns with contemporary educational paradigms that prioritize data-driven learning, critical thinking, and interdisciplinary competence.

Moreover, the study demonstrates that digital technologies—such as online data platforms, spreadsheets, and GIS tools—play a crucial role in facilitating statistical integration. These technologies enable exploratory learning environments where students actively construct knowledge through analysis, visualization, and inquiry. As a result, statistics becomes a powerful driver of student motivation and engagement, particularly when linked to socially relevant geographic topics.

Despite these benefits, the research also reveals persistent challenges, including limited teacher preparedness, curriculum overload, and inconsistent methodological practices. Addressing these issues requires targeted teacher training programs, curriculum reforms that explicitly incorporate statistical competencies, and the development of practical pedagogical models that support classroom implementation.

Overall, this study contributes to geography education research by proposing a theoretically grounded and practically applicable framework for using statistics in high school geography classes. The results suggest that statistics should be recognized as a core methodological component of modern geographic education, essential for preparing students to navigate an increasingly complex, data-driven, and interconnected world.

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DIGITAL TECHNOLOGIES AS A TOOL FOR TEACHING SPATIAL DIMENSIONS OF SOCIAL INEQUALITY

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Abstract

This research investigates the role of digital technologies as effective tools in teaching the spatial dimensions of social inequality within geography education. With the rise of geographic information systems (GIS), interactive digital mapping, and online geospatial learning platforms, educators now have greater capacity to engage students in analyzing complex patterns of socio-spatial disparities. The objective of this study is to develop and evaluate a teaching methodology that integrates digital geographic technologies into classroom practices to enhance learners' spatial reasoning, critical analysis, and understanding of how social inequalities manifest across regions. Using a mixed-methods approach combining pedagogical intervention, student performance assessment, and qualitative feedback, the study demonstrates that digital tools significantly improve students' ability to interpret spatial data, recognize regional inequalities in access to resources and services, and apply geographic concepts to real-world issues. Findings highlight that digital technologies foster active learning, encourage student participation, and contribute to deeper comprehension of socio-spatial phenomena. The paper concludes with practical recommendations for implementing digital geographic resources in diverse educational settings, emphasizing their potential to transform geography instruction and prepare students for competency in analyzing socio-spatial inequality.

Keywords: digital technologies, spatial dimensions, social inequality, geography education, GIS, interactive maps.

Introduction. Digital technologies have become an increasingly powerful set of tools for teaching the spatial dimensions of social inequality in contemporary education. Advances in geographic information systems (GIS), digital mapping, and spatial analysis allow educators and students to visualize, analyze, and critically interpret how social inequalities are produced, distributed, and sustained across geographic space. By transforming abstract social concepts into observable spatial patterns, digital technologies support deeper engagement with issues of equity, access, and regional disparity within geography education.

GIS-based research has demonstrated the pedagogical value of spatial analysis in revealing uneven access to essential services. For example, mapping access to primary schools can expose patterns of unequal service provision and highlight marginalized urban peripheries, such as immigrant neighborhoods in Ain Touda, Algeria (Akakba & Lahmar, 2023). Through techniques such as nearest-neighbour analysis, hotspot mapping, and service-area modelling, students are able to examine how distance, accessibility, and spatial distribution contribute to social disadvantage. These methods encourage learners to move beyond descriptive analysis toward a critical understanding of how inequality is embedded in spatial structures and planning decisions.

More broadly, digital mapping and spatial analysis have long been used to assess housing conditions, infrastructure needs, and service accessibility, helping learners connect theoretical discussions of social equity with tangible inequalities in everyday life (Baker, 2000). Within educational contexts, such applications enable students to link geographic concepts with real-

world socio-economic challenges, fostering spatial thinking and analytical skills. Recent work on spatial justice in GIS education further illustrates how national-scale datasets on intergenerational mobility, poverty, and residential segregation can be incorporated into classroom projects to explore structural inequality across regions (Talen & Koschinsky, 2014, cited in *Spatial Justice – GIS at Tufts*). These approaches emphasize the role of geography education in cultivating critical awareness of systemic and spatially embedded forms of inequality.

In parallel with GIS-based methods, immersive digital technologies such as virtual reality (VR) and augmented reality (AR) are increasingly employed in inclusive education to create adaptable and interactive learning environments. Recent studies highlight the potential of VR to support learners with diverse disabilities by offering flexible representations of space and personalized learning experiences (Kovalenko et al., 2025). Policy-oriented analyses suggest that, when designed with equity and inclusion in mind, immersive technologies can enhance participation, representation, and accessibility in digital learning spaces, thereby linking technological innovation with broader questions of social and educational justice (Castro & Bennett, 2021).

Despite the growing body of research on digital technologies, spatial analysis, and social inequality, there remains a need for systematic pedagogical frameworks that integrate these tools into geography education in a coherent and effective manner. In particular, limited attention has been paid to how digital geographic technologies can be explicitly used to teach the spatial dimensions of social inequality and to develop students' capacity for critical socio-spatial analysis.

Therefore, the aim of this study is to examine the role of digital technologies as tools for teaching the spatial dimensions of social inequality and to propose a methodological approach for their integration into geography education. The study seeks to evaluate how GIS, interactive maps, and digital learning environments contribute to the development of students' spatial thinking, analytical skills, and understanding of socio-spatial disparities.

Literature Review. The literature on digital technologies and the spatial dimensions of social inequality can be grouped into three interconnected strands: research on GIS and spatial analysis, studies of immersive digital technologies in geography education, and work on digital equity and the digital divide in schooling. Together, these studies explain how digital tools can both reveal and potentially reproduce socio-spatial inequalities.

The first strand highlights the role of geographic information systems (GIS) and spatial analysis in identifying inequalities embedded in the distribution of infrastructure and services. GIS-based mapping of education, housing, and public services makes visible the spatial organisation of advantage and disadvantage. For example, a case study from Ain Touta, Algeria, demonstrates how nearest-neighbour, hotspot, and service-area analyses reveal low accessibility to primary schools in immigrant neighbourhoods, exposing the spatial production of educational disadvantage (Akakba & Lahmar, 2019). Similar approaches are widely applied to visualise disparities in access to services, and recent educational studies show that integrating GIS and interactive maps into geography lessons significantly improves students' spatial analytical skills and understanding of socio-spatial inequality (Perez & Gonzalez, 2022, cited in *Science and Innovation*, 2023). These findings underline the pedagogical value of GIS as both an analytical and instructional tool.

A second strand focuses on immersive and interactive digital technologies, particularly virtual reality (VR), augmented reality (AR), and geo-virtual reality (GVR), in geography education. Research suggests that virtual field trips enhance students' engagement with place-based learning while introducing new spatial and perceptual dimensions that require critical reflection (Budke & Kuckuck, 2019; Jung, 2019). Empirical studies report increased student motivation, participation, and spatial reasoning when VR and AR are used, especially when combined with GIS and interactive mapping, resulting in learning gains of approximately 20–30 percent (Karimov et al., 2020; *Science and Innovation*, 2023). Importantly, this literature emphasises that immersive

technologies should support critical geographic inquiry rather than function solely as experiential tools (Grevsmühl & Pohl, 2021).

The third strand addresses digital equity and the risk that digital technologies may reinforce existing social and spatial inequalities. Research on the digital divide shows that unequal access to digital devices, connectivity, and ICT skills—often shaped by socio-economic status and migration background—strongly influences who benefits from digital learning (van Deursen & Helsper, 2022). These inequalities became particularly evident during periods of rapid digitalisation, such as the COVID-19 pandemic. Policy analyses, including those by the OECD, argue that while digital technologies can promote more inclusive education when designed for flexibility and accessibility, persistent gaps in access and digital competencies continue to disadvantage vulnerable learners (OECD, 2023).

Overall, the reviewed literature demonstrates that GIS, immersive technologies, and digital learning platforms offer strong potential for teaching and visualising the spatial dimensions of social inequality. At the same time, it highlights the need for pedagogical approaches that integrate digital geographic technologies while explicitly addressing issues of equity, access, and inclusion.

Methodology / Research Design. This study employs a mixed-methods research design to examine the effectiveness of digital technologies in teaching the spatial dimensions of social inequality in geography education. The research was conducted within an undergraduate geography course and integrated into the regular curriculum.

The instructional intervention involved the use of geographic information systems (GIS), interactive digital maps, and web-based geospatial platforms. Learning activities focused on analysing spatial patterns of social inequality related to access to education, public services, and infrastructure. Students completed tasks such as service-area mapping, distance analysis, and thematic mapping to identify regional disparities.

Data collection combined quantitative and qualitative methods. Quantitative data were obtained through pre- and post-instruction assessments measuring students' spatial thinking and understanding of socio-spatial inequality. Qualitative data were collected through short student reflections and open-ended questionnaires to capture perceptions of digital tool use.

Quantitative data were analysed using descriptive and comparative analysis, while qualitative responses were examined through thematic coding. Data triangulation was applied to ensure reliability. Ethical standards were observed, with voluntary participation and anonymity guaranteed.

Results and Discussion. The results of this study indicate that the integration of digital geographic technologies significantly enhances students' understanding of the spatial dimensions of social inequality. Across learning activities involving GIS, interactive maps, and digital spatial analysis tasks, students demonstrated measurable improvements in spatial reasoning, data interpretation, and critical engagement with socio-spatial patterns. These findings align with prior research emphasizing the pedagogical value of digital mapping and GIS in geography education (Perez & Gonzalez, 2022).

One key result concerns students' ability to interpret spatial distributions of inequality. After engaging with GIS-based exercises—such as mapping access to educational facilities, analyzing service areas, and identifying spatial clusters of disadvantage—students showed a stronger capacity to explain how distance, infrastructure distribution, and urban structure contribute to unequal access to opportunities. Rather than viewing social inequality as an abstract or purely economic phenomenon, learners increasingly conceptualized it as a spatially produced and geographically structured process. This supports earlier findings that spatial visualization enables learners to connect social theory with concrete geographic evidence (Akakba & Lahmar, 2019).

The use of interactive maps also led to notable gains in students' analytical and critical thinking skills. By manipulating layers, comparing regions, and exploring multiple indicators simultaneously, students were able to identify overlapping forms of inequality, such as the relationship between educational access, residential location, and socio-economic status. These outcomes confirm that digital mapping tools encourage exploratory learning and support deeper engagement with complex spatial data, consistent with the literature on GIS-supported inquiry-based learning.

In addition, results suggest that combining GIS with immersive and interactive digital environments enhances student engagement and motivation. Learners reported higher levels of interest and participation when spatial inequality was explored through visually rich and interactive formats rather than static maps or textual descriptions. This finding echoes previous studies showing that immersive technologies, when integrated with spatial analysis, can improve learning efficiency and conceptual understanding by approximately 20–30 percent (Karimov et al., 2020). Importantly, the effectiveness of these technologies depended on their pedagogical framing. When digital tools were explicitly linked to critical questions about equity, access, and justice, students were more likely to reflect on the social implications of spatial patterns rather than treating the technologies as purely technical or representational tools.

The discussion of results also highlights several challenges related to digital equity. While most students benefited from digital geographic technologies, differences in prior digital skills and access to reliable hardware occasionally limited participation for some learners. These findings resonate with research on the digital divide, which emphasizes that unequal access to digital competencies and infrastructure can shape learning outcomes in technology-rich environments (van Deursen & Helsper, 2022). Consequently, the results underscore the importance of providing institutional support, scaffolding digital skills, and ensuring equitable access to technological resources when implementing GIS and interactive mapping in education.

Overall, the findings suggest that digital technologies function not only as instructional tools, but also as mediators of critical socio-spatial understanding. When thoughtfully integrated into geography education, GIS, interactive maps, and immersive digital environments enable students to visualize, analyze, and critically interpret the spatial dimensions of social inequality. At the same time, the results reinforce the argument that digital pedagogy must remain attentive to issues of access, inclusion, and digital equity in order to avoid reproducing the very inequalities it seeks to expose.

Conclusion. This study demonstrates that digital technologies offer effective tools for teaching and analysing the spatial dimensions of social inequality in education. GIS-based analysis clearly reveals uneven access to primary schools, as illustrated by the case of Ain Touta, where immigrant-dominated northern districts experience the lowest educational accessibility, reinforcing existing spatial inequalities (Akakba & Lahmar, 2019). Visualisation through hotspot and service-area analysis enables learners and educators to understand how urban structure and planning decisions shape unequal educational opportunities and supports discussion of more equitable spatial and transport policies.

In addition, findings from the use of virtual reality (VR) indicate that immersive digital environments can enhance accessibility and engagement in the classroom, particularly for students with special educational needs. Well-designed VR-based learning activities improve participation and support the development of cognitive, social, and motor skills compared to conventional teaching approaches (Kovalenko et al., 2025). However, evidence from the digital equity literature highlights that these benefits depend on adequate infrastructure, teacher training, and inclusive design. Persistent inequalities in access to devices, connectivity, and digital competencies may otherwise limit the equity-enhancing potential of GIS and VR technologies (OECD, 2023).

Overall, the study suggests that educational practice should combine GIS-based analysis to diagnose socio-spatial inequalities with the use of immersive digital tools to promote inclusive learning environments, while simultaneously addressing digital equity to ensure that the benefits of technological innovation reach disadvantaged learners and communities.

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Methods of using artificial intelligence technologies in project-based learning in the Fundamentals of Geoeconomics section of school geography

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Abstract

The rapid advancement of artificial intelligence (AI) technologies has significantly transformed contemporary educational practices, positioning AI as a key instrument for knowledge construction, data analysis, and digital innovation in school education. Beyond its technical functions, AI increasingly influences pedagogical models, learning personalization, and the development of higher-order cognitive skills. This study examines the role of artificial intelligence technologies in project-based learning within the “Fundamentals of Geoeconomics” section of school geography, focusing on their potential to enhance students’ understanding of spatial-economic processes and global economic interdependencies.

The research adopts an integrated analytical framework that combines insights from digital pedagogy, constructivist learning theory, and geoeconomic education. Drawing on educational practice, curriculum documents, and classroom-based project activities, the study employs comparative and qualitative analysis to assess how the integration of AI-based tools relates to students’ learning outcomes across different instructional contexts. Particular attention is given to the role of AI in supporting information processing, data visualization, scenario modeling, and decision-making in geoeconomic projects.

The findings indicate that the use of AI technologies in project-based learning contributes to improved student engagement, critical thinking, and problem-solving skills. AI-supported projects are shown to facilitate deeper conceptual understanding of regional development, spatial inequalities, and global economic dynamics by enabling students to work with real-world datasets and simulate alternative development scenarios. However, the results also reveal that the benefits of AI integration are unevenly distributed. Educational environments with higher levels of digital infrastructure, teacher preparedness, and technological accessibility benefit disproportionately, while less-resourced schools face structural constraints that may limit the effectiveness of AI-based instruction.

This study contributes to the literature on digital geography education by synthesizing pedagogical, technological, and spatial-economic perspectives within a project-based learning framework. The findings underscore the need for coordinated educational policies and teacher training programs that promote inclusive and ethically informed access to artificial intelligence technologies, ensuring that AI supports balanced, meaningful, and sustainable learning in school geography.

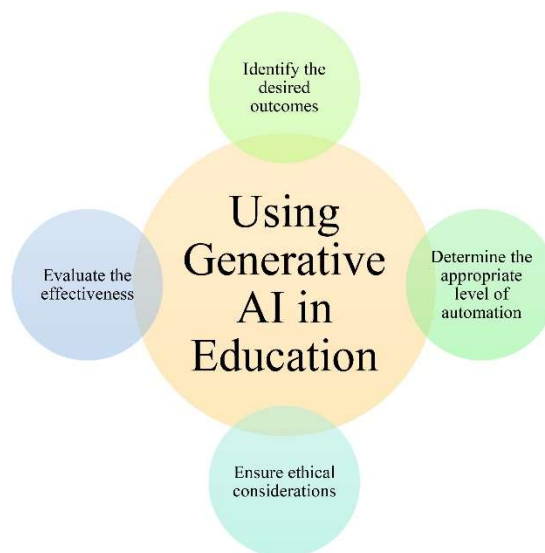
Keywords

Artificial intelligence in education; project-based learning; geoeconomics education; digital transformation; spatial-economic analysis; educational innovation; data-driven learning; geography teaching methods.

Introduction

The rapid digital transformation of contemporary society has fundamentally reshaped educational systems, teaching methodologies, and learning environments across the world. Advances in artificial intelligence (AI) technologies have accelerated this transformation by enabling new forms of knowledge production, personalized learning, and intelligent data processing. Within the field of school education, AI is increasingly recognized not merely as a technological tool, but as a pedagogical instrument capable of enhancing cognitive engagement, critical thinking, and interdisciplinary learning.

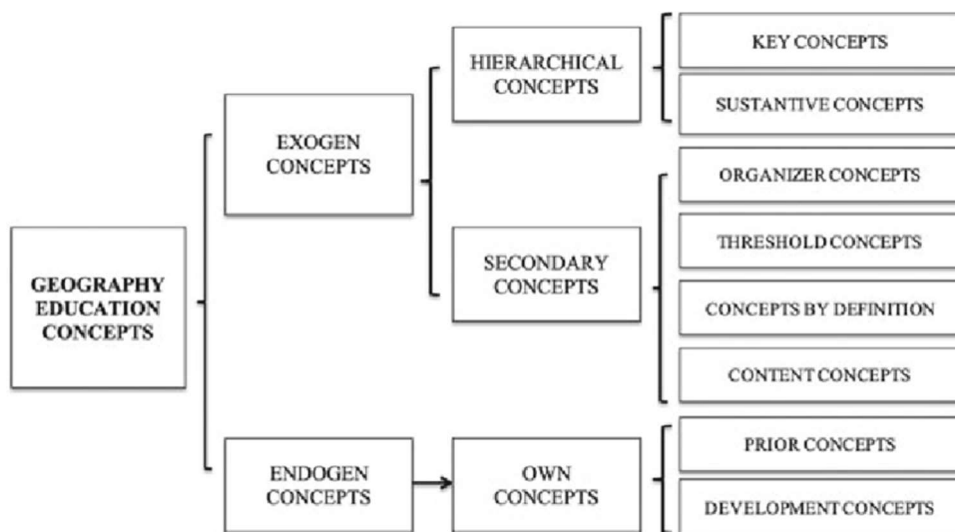
In geography education, this transformation is particularly evident in the growing emphasis on data-driven learning and spatial-economic analysis. Modern geography curricula increasingly require students to interpret complex socio-economic data, analyze regional development patterns, and understand global economic interdependencies. The “Fundamentals of Geoeconomics” section of school geography plays a central role in this process, as it introduces learners to key concepts such as global trade, economic globalization, regional inequality, resource distribution, and geopolitical competition. However, traditional teaching methods often struggle to convey these abstract and dynamic processes in meaningful and engaging ways.



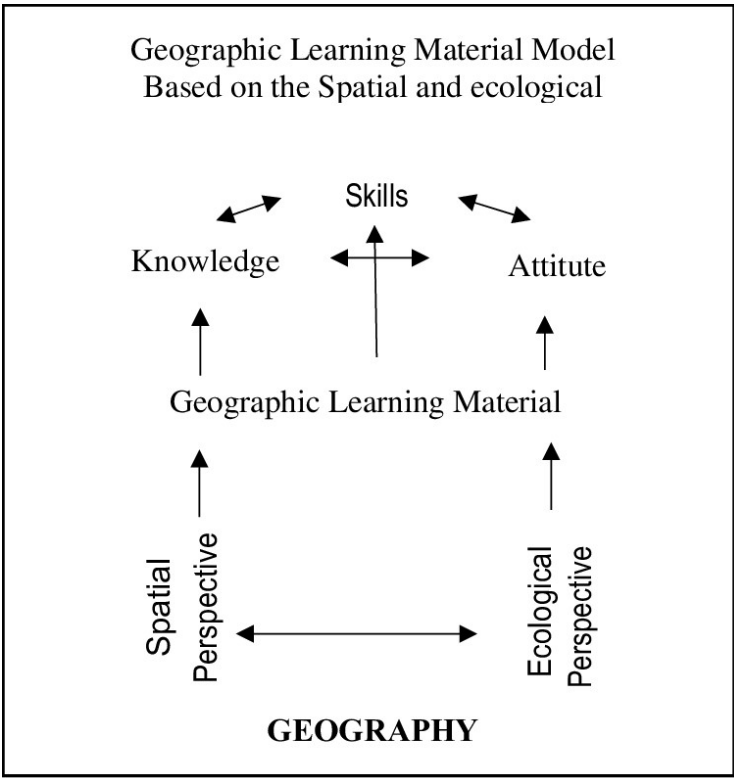
Project-based learning (PBL) has emerged as an effective pedagogical approach for addressing these challenges. PBL emphasizes student-centered inquiry, collaborative problem-solving, and the application of knowledge to real-world situations. Through project activities, students actively construct understanding by investigating authentic problems, collecting and analyzing data, and presenting evidence-based solutions. In the context of geoeconomics, PBL enables learners to explore real economic scenarios, such as international trade networks, investment flows, or development strategies, thereby enhancing conceptual understanding and practical relevance.



Artificial intelligence technologies significantly extend the potential of project-based learning in geography. AI tools—such as intelligent tutoring systems, generative AI platforms, data analytics software, and digital mapping applications—provide students with advanced capabilities for information retrieval, data processing, and scenario modeling. These tools enable learners to interact with large datasets, identify hidden patterns, and simulate alternative economic outcomes, transforming passive learning into active knowledge construction.

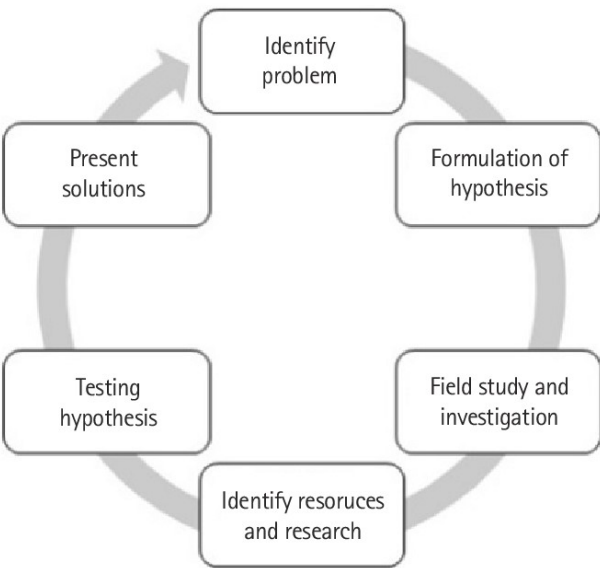


At the same time, the integration of AI into school education raises important pedagogical, ethical, and methodological questions. While AI offers opportunities for personalized learning and cognitive support, it also introduces risks related to algorithmic bias, data privacy, and unequal access to technological resources. Moreover, many teachers face challenges in adopting AI-based methods due to limited training, lack of institutional support, and uncertainty regarding assessment strategies.



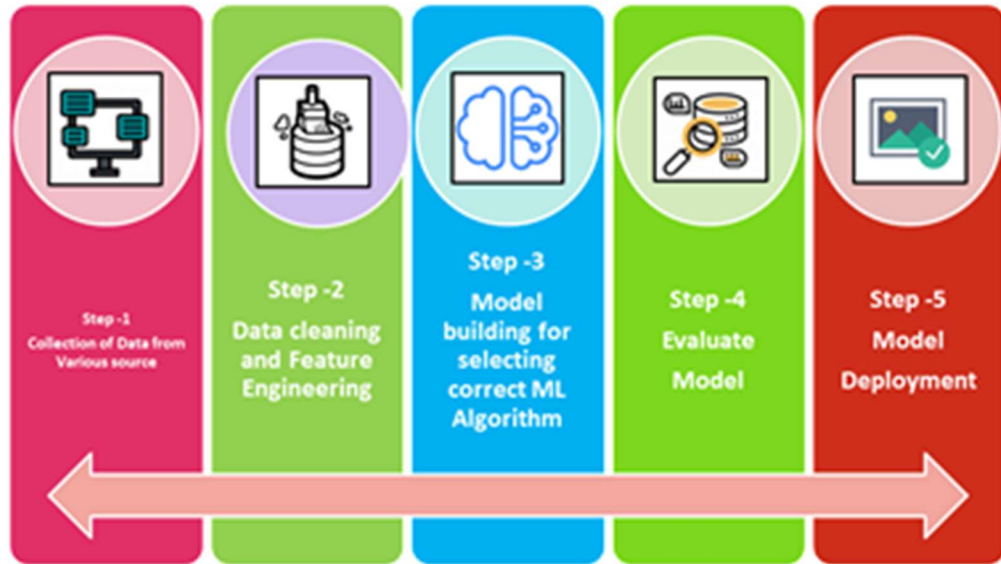
Against this background, there is a growing need for systematic research that explores how artificial intelligence technologies can be effectively integrated into project-based learning in geography education. In particular, empirical and methodological studies focusing on geoeconomics remain limited, despite the increasing relevance of this field in understanding global development and inequality.

Therefore, this study aims to examine the methods of using artificial intelligence technologies in project-based learning within the “Fundamentals of Geoeconomics” section of school geography. The research seeks to identify pedagogically grounded strategies for integrating AI tools into classroom practice, evaluate their impact on students’ learning outcomes, and analyze the conditions under which AI-supported instruction can contribute to meaningful, inclusive, and sustainable geography education.



Literature Review

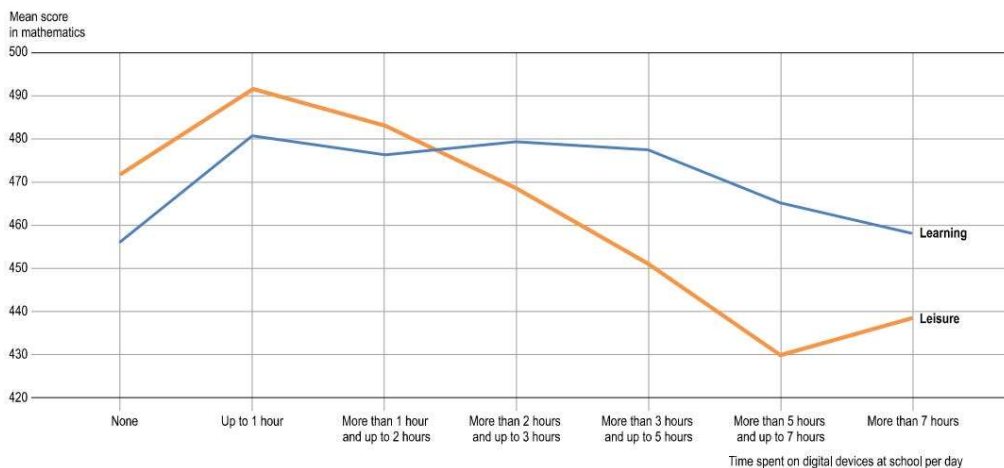
The integration of artificial intelligence into education has been widely discussed in contemporary pedagogical research, particularly in relation to personalized learning, adaptive instruction, and intelligent knowledge management. AI in education is commonly defined as the use of machine-based systems capable of performing tasks that normally require human intelligence, such as reasoning, learning, decision-making, and pattern recognition. In educational contexts, AI technologies are increasingly applied to support student-centered learning, automate feedback, and enhance data-driven instructional practices.



From a theoretical perspective, this study is grounded in **constructivist learning theory**, which emphasizes that learners actively construct knowledge through interaction with meaningful learning environments. According to constructivist principles, learning is most effective when students engage in inquiry, problem-solving, and reflective thinking. Project-based learning aligns closely with this paradigm by positioning students as active participants who explore real-world problems and generate knowledge through investigation and collaboration.

Figure II.5.14. Time spent on digital devices at school and mathematics performance

Based on students' reports; OECD average



Note: Differences between categories are all statistically significant (see Annex A3). Source: OECD, PISA 2022 Database, Annex B1, Chapter 5.

In addition, the study draws on **digital pedagogy theory**, which conceptualizes digital technologies as cognitive mediators that reshape learning processes rather than simply delivering

content. Digital pedagogy highlights the role of technology in facilitating new forms of interaction, representation, and meaning-making. Within this framework, artificial intelligence is viewed as an intelligent mediator that supports learners' cognitive processes by organizing information, suggesting analytical pathways, and scaffolding complex tasks.

Integrated School Effectiveness Model	Dynamic School Effectiveness Model	Framework of Indicators
<u>Context-Level Factors</u> <ul style="list-style-type: none"> • Achievement stimuli from higher administrative levels • Development of educational consumerism; • Co-variables like school size, student-body composition, school category, and urban/rural distinctions <u>School-Level Factors</u> <ul style="list-style-type: none"> • Achievement-oriented policy • Educational leadership • Consensus, co-operative planning of teachers • Quality of school curricula in terms of content covered, and formal structure • Pressure for achievement; • Recruitment of qualified staff • Financial and material Characteristics of the school • Orderly atmosphere • Evaluative potential <u>Classroom-Level Factors</u> <ul style="list-style-type: none"> • Time on task • Structured teaching • Opportunity to learn • High expectations of pupils' progress • Evaluation and monitoring of pupils' progress • Reinforcement 	<u>Context-Level Factors</u> <ul style="list-style-type: none"> • National/regional policy for education • Evaluation of policy • Educational environment <u>School-Level Factors</u> <ul style="list-style-type: none"> • School policy and evaluation of school policy <u>Classroom-Level Factors</u> <ul style="list-style-type: none"> • Quality of teaching (orientation, structuring, modelling, application, questioning, assessment, management of time, classroom as a learning environment) <u>Student-Level Factors</u> <ul style="list-style-type: none"> • Aptitude • Perseverance • Time on task • Opportunity to learn • Socio-Economic Status • Gender • Ethnicity • Personality traits • Expectations • Thinking style • Subject motivation 	<u>Context-Level Factors</u> <ul style="list-style-type: none"> • National policy for education • Evaluation mechanism for educational policy • National educational environment (e.g., educational consumerism, school category) • External achievement stimuli <u>School-Level Factors</u> <ul style="list-style-type: none"> • School policies and practices • School climate • Educational leadership • School resources <u>Classroom-Level Factors</u> <ul style="list-style-type: none"> • Demographic profile • Professional development • Appraisal and feedback • Self-efficacy • School climate • Classroom Management (Climate) • Effective teaching components • Homework • Tests • ICT <u>Student-Level Factors</u> <ul style="list-style-type: none"> • Gender • Age • Socio-Economic Status • Motivation • Self-efficacy • Self-regulation • Learning preferences

A third theoretical foundation of this research is **spatial thinking theory**, which is particularly relevant for geography education. Spatial thinking involves the ability to understand spatial relationships, recognize patterns, and interpret geographic phenomena through maps, models, and spatial data. In geoeconomics, spatial thinking enables students to analyze regional inequalities, global economic networks, and geopolitical dynamics. AI technologies enhance spatial thinking by enabling automated spatial analysis, geovisualization, and scenario simulation.

Together, these theoretical perspectives position artificial intelligence not as a replacement for human teaching, but as a **cognitive partner** that supports inquiry-based learning and higher-order thinking in geography education.

Project-based learning is widely recognized as one of the most effective instructional approaches for developing twenty-first-century skills, including critical thinking, collaboration, creativity, and problem-solving. In PBL environments, students engage in extended learning processes that involve identifying problems, collecting data, analyzing information, and presenting solutions. Such processes require high levels of autonomy, reflection, and analytical reasoning.

Artificial intelligence significantly enhances the effectiveness of project-based learning by providing students with advanced analytical tools and personalized learning support. AI systems can assist learners in several key stages of the project cycle:

1. **Problem formulation** – AI tools help students explore background information, generate research questions, and identify relevant data sources.
2. **Data collection and processing** – AI platforms enable automated data retrieval, filtering, and organization from large online datasets.
3. **Analysis and modeling** – AI supports statistical analysis, trend detection, correlation analysis, and scenario modeling.
4. **Presentation and reflection** – Generative AI tools assist in summarizing findings, creating visualizations, and structuring project reports.

In the context of geoeconomics, these functions allow students to analyze global trade flows, investment patterns, development indicators, and regional disparities using authentic data. For example, students may use AI tools to simulate the economic impact of infrastructure development in different regions or model alternative scenarios of economic integration.

Empirical studies indicate that AI-supported project-based learning increases students' engagement, self-regulation, and conceptual understanding. Learners demonstrate greater motivation when they are able to interact with intelligent systems that respond to their individual learning needs and provide real-time feedback.

Methodological Design of the Study

This study adopts a **mixed-methods research design** aimed at exploring the pedagogical effectiveness of artificial intelligence in project-based geoeconomics learning. The research combines quantitative and qualitative approaches to capture both learning outcomes and learning processes.

The quantitative component involves pre-test and post-test assessments of students' knowledge and skills related to geoeconomic concepts. These assessments measure students' ability to interpret economic data, analyze spatial patterns, and apply theoretical knowledge to practical scenarios.

The qualitative component includes classroom observations, student interviews, and teacher reflections. These methods provide insights into students' cognitive engagement, learning strategies, and perceptions of AI-supported learning. Qualitative data are analyzed using thematic analysis to identify recurring patterns in learning experiences.

The study sample consists of high school students from different educational backgrounds who participated in project-based geoeconomics modules supported by AI technologies. Teachers received preliminary training on AI tools and project-based instructional strategies.

Findings and Discussion

The findings of the study indicate that artificial intelligence technologies significantly enhance the quality of project-based learning in geoeconomics. Students who participated in AI-supported projects demonstrated higher levels of engagement, deeper conceptual understanding, and improved analytical skills compared to those in traditional instructional settings.

AI tools were particularly effective in supporting data analysis and scenario modeling. Students were able to explore complex economic relationships that would otherwise be inaccessible due to cognitive or technical limitations. For example, AI-enabled simulations allowed learners to visualize the long-term effects of economic policies on regional development.

However, the results also revealed several challenges. Some students experienced difficulties related to digital literacy and critical evaluation of AI-generated information. In addition, teachers reported concerns regarding ethical issues, such as data reliability, algorithmic bias, and academic integrity.

These findings suggest that while AI offers powerful pedagogical opportunities, its integration must be accompanied by **methodological guidance, ethical awareness, and teacher training**.

Implications for Geography Education

The results of this study have important implications for curriculum design and teacher professional development. Geography curricula should incorporate AI-based competencies as core learning outcomes, particularly in subjects dealing with complex socio-economic systems.

Teacher education programs should include training modules on AI literacy, digital ethics, and project-based instructional strategies. Without adequate pedagogical preparation, the educational potential of AI may remain underutilized.

Furthermore, educational policies should promote equitable access to digital infrastructure to prevent the emergence of new forms of educational inequality.

Conclusion

This study demonstrates that artificial intelligence technologies, when integrated into project-based learning, significantly enhance students' understanding of geoeconomic processes and spatial-economic relationships. AI functions as a cognitive mediator that supports inquiry, analysis, and reflection, transforming traditional geography education into a dynamic, data-driven learning environment.

However, the effectiveness of AI depends on pedagogical design, teacher competence, and ethical implementation. AI should not replace human teaching but should complement it by extending learners' cognitive capacities.

Ultimately, the integration of artificial intelligence into geoeconomics education represents not merely a technological innovation, but a **paradigm shift in how geographic knowledge is constructed, interpreted, and applied in the digital age.**

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WATER RESOURCES OF KAZAKHSTAN: CURRENT STATUS AND MANAGEMENT CHALLENGES

Gulmira Berdygulova

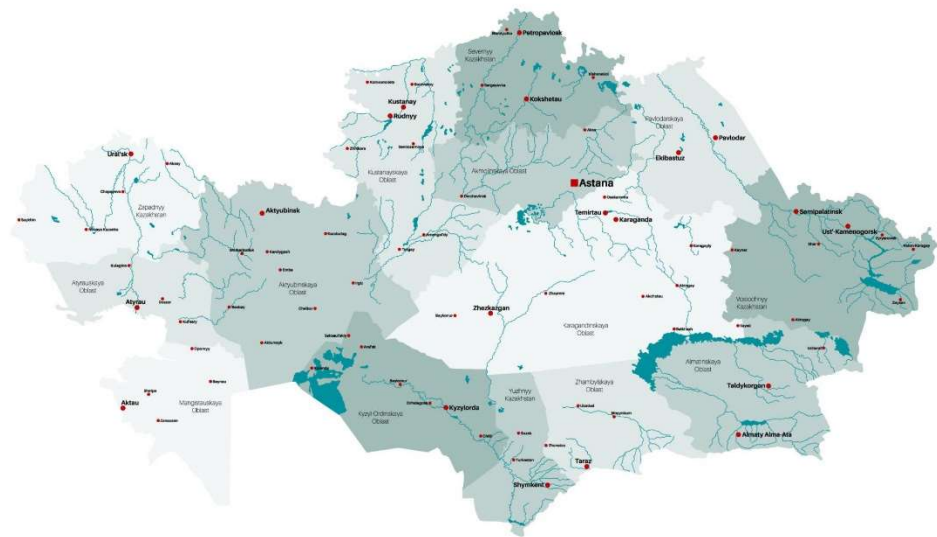
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Abstract

The article examines the water resources of the Republic of Kazakhstan, their current quantitative and qualitative status, as well as key water management challenges under conditions of climate change and increasing water demand. The study is based on the analysis of hydrological, statistical, and analytical data reflecting the present state of surface and groundwater resources. Particular attention is paid to regional water availability, the transboundary nature of river runoff, and the impact of economic activities on water quality. The results indicate that the main challenges facing Kazakhstan's water sector include declining water resources, uneven spatial distribution, pollution of water bodies, and insufficient efficiency of the existing water management system. The paper emphasizes the necessity of implementing integrated water resources management principles, improving monitoring systems, and strengthening international cooperation on transboundary water use. The findings of the study can be applied in the development of strategic planning documents and practical measures aimed at enhancing water security and ensuring sustainable development of the Republic of Kazakhstan.

Keywords: water resources, water availability, water resources management, transboundary waters, water security, Kazakhstan

Introduction. Water resources constitute a foundational component of environmental sustainability and socio-economic development, particularly in arid and semi-arid regions where availability is intrinsically limited. Kazakhstan is characterized by low per capita renewable freshwater resources relative to global averages, significant interannual and spatial variability, and high dependence on transboundary river inflows originating outside national borders [Prniyazova & Volkov, 2024; Medetov et al., 2018]. Approximately 45 % of Kazakhstan's available surface water is derived from rivers shared with neighbouring states, including the Irtysh, Ili, Syr Darya and Ural basins, exposing national water security to external hydrological pressures and political complexities [Medetov et al., 2018].



Anthropogenic climate change has increasingly altered hydrological regimes across the Central Asian continent over recent decades, manifesting in temperature rise, shifts in precipitation patterns, glacier retreat and modifications to seasonal runoff distribution [Lee et al., 2023; Saparova et al., 2021]. Future climate projections indicate continued vulnerability of freshwater resources in Kazakhstan, with modelled changes suggesting both quantitative and qualitative shifts that pose challenges to existing water resource infrastructure and planning frameworks [Lee et al., 2023]. These climatic pressures are compounded by intensifying anthropogenic demands from agricultural irrigation, industrial development and urban expansion, which augment consumptive water use and contribute to pollution loads in both surface and groundwater systems [Riabtsev & Akhmetov, 2023].

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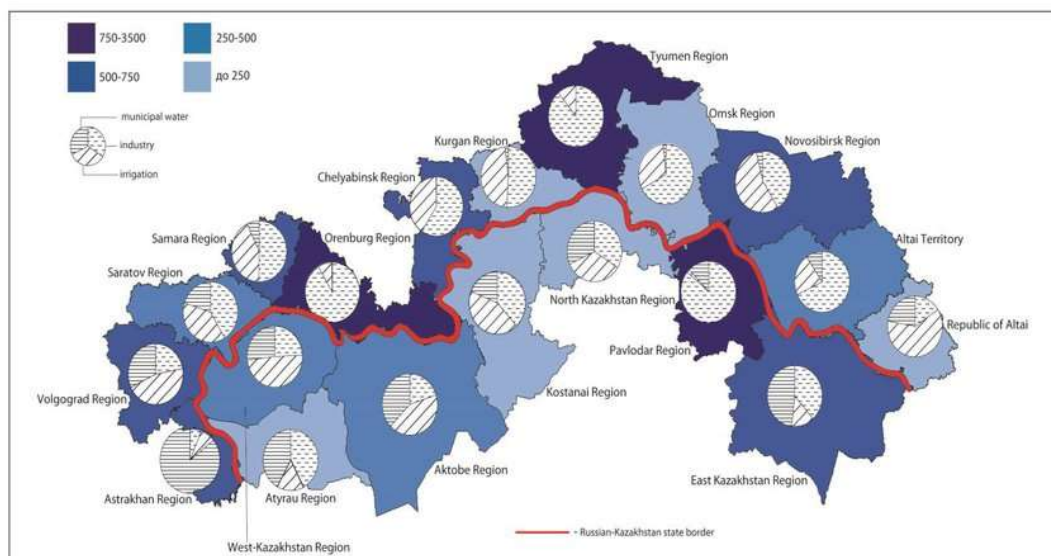
Despite the criticality of these issues, institutional and governance frameworks in Kazakhstan have lagged behind evolving environmental challenges. Existing legal and administrative structures exhibit fragmentation and limited integration, hindering the effective operationalization of holistic water governance principles, including those of Integrated Water Resources Management (IWRM) [Khamzayeva & Baikushikova, 2024; Myrzahmetov et al., 2023]. Scientific consensus underscores the need for enhanced policy frameworks that address multi-scalar water allocation, monitoring, and transboundary cooperation. Strengthening institutional capacity, improving data integration, and adopting adaptive, evidence-based management

strategies are identified as essential for ensuring long-term water sustainability in the face of climatic and socio-economic pressures [Khamzayeva & Baikushikova, 2024; Myrzahmetov et al., 2023].



This study aims to provide a comprehensive assessment of the current state of water resources in Kazakhstan and to analyse the principal challenges in their governance. By integrating hydrological, climatic and policy dimensions, the research seeks to contribute empirical evidence for the formulation of resilient water management strategies under conditions of ongoing environmental change.

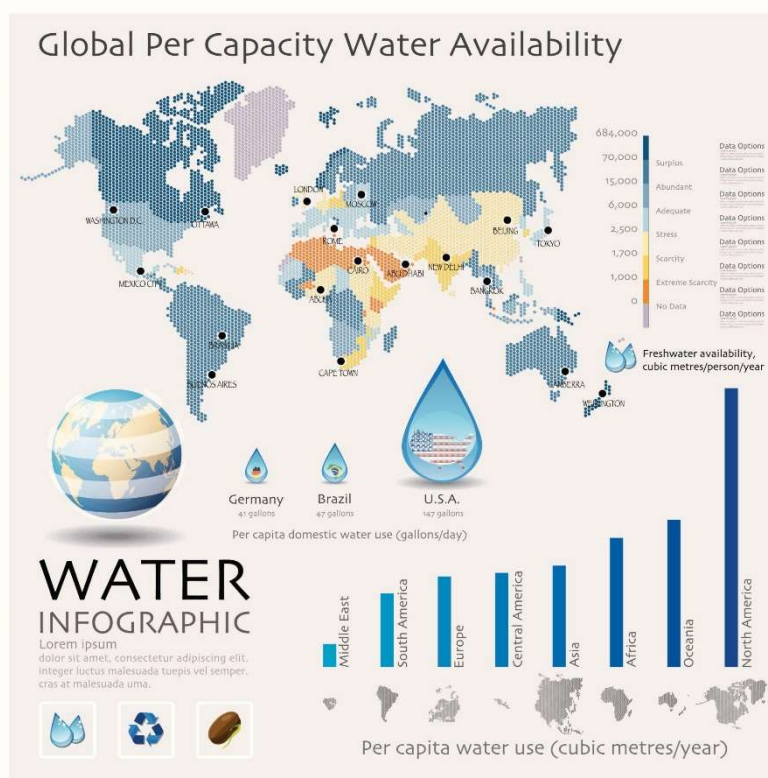
Literature Review. Recent research highlights that water resource availability in Kazakhstan is limited by arid climatic conditions, uneven spatial distribution, and a high dependency on transboundary river inflows. Prniyazova and Volkov (2024) analyze the implementation of Integrated Water Resources Management (IWRM) in Central Asia, identifying institutional fragmentation and insufficient cooperation across riparian states as key barriers to effective water governance.



Medetov et al. (2018) further examine legal and institutional arrangements for transboundary water management in Kazakhstan, noting that, despite formal agreements,

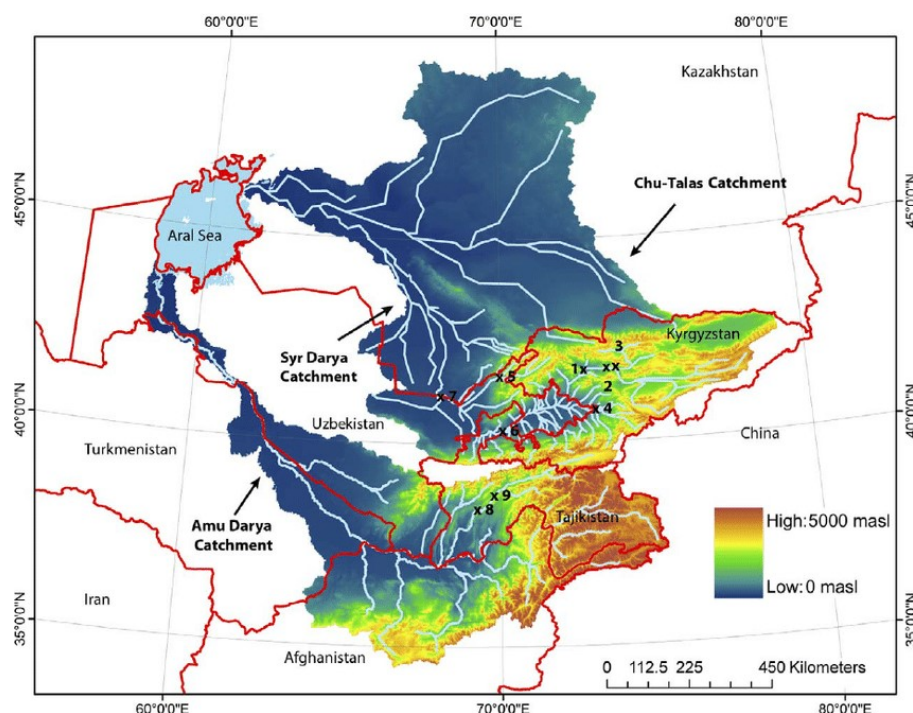
mechanisms for data exchange and enforcement are weak, leading to inequitable water allocation.

Climate-induced hydrological changes have also been documented. Lee et al. (2023) use hydrological modelling to demonstrate that rising temperatures and altered precipitation patterns are significantly affecting seasonal runoff in the main river basins. Similarly, Saparova et al. (2021) show that glacier retreat and increased interannual variability of discharge reduce reliability of water supply systems.



Riabtsev and Akhmetov (2023) address socio-economic pressures, reporting intensified irrigation and industrial water withdrawals alongside persistent pollution problems. Governance and strategic planning challenges are discussed by Khamzayeva and Baikushikova (2024) and Myrzahmetov et al. (2023), who argue that implementation of IWRM principles is limited by fragmented institutional responsibilities and insufficient monitoring systems.

Overall, these studies indicate a combination of climatic, transboundary, and governance-related issues affecting Kazakhstan's water resources, while comprehensive integrated assessments remain limited.



Methodology / Research Design. The research employs a multi-level, integrative methodology designed to comprehensively assess the state of water resources in Kazakhstan and analyze the effectiveness of existing governance structures. The methodological framework integrates hydrological, climatic, geospatial, and socio-institutional analyses, allowing a holistic understanding of both natural and anthropogenic factors influencing water availability.

The study focuses on the principal river basins of Kazakhstan, including the Irtysh, Ili, Syr Darya, Ural, and Ishim, which collectively represent the majority of the country's freshwater resources. Both surface water and groundwater systems are considered, accounting for interannual variability, seasonal distribution, and regional disparities in water availability and consumption. Temporal coverage extends from 2000 to 2023, enabling the identification of long-term trends, shifts in hydrological regimes, and the influence of climatic and anthropogenic factors on water resources.

➤ *Data collection* combined multiple sources to ensure accuracy and comprehensiveness. Hydrological data, including river discharge, reservoir storage, and groundwater levels, were obtained from the Kazakhstan Hydrometeorological Service. Climatic variables such as precipitation, air temperature, and glacier mass balance were collected from the World Meteorological Organization and national climate reports. Socio-economic information, including agricultural, industrial, and municipal water use, was obtained from national statistical agencies. Institutional and governance data were collected from national legislation, transboundary water agreements, and policy documents related to Integrated Water Resources Management (IWRM).

➤ *Hydrological and statistical analyses* formed the core of the quantitative methodology. Time-series analyses were conducted to evaluate trends in river discharge, reservoir levels, and groundwater availability. Variability metrics were calculated to assess both intra-annual and interannual fluctuations, providing insights into the stability and reliability of water resources under changing climatic conditions. Spatial analysis using Geographic Information Systems (GIS) allowed mapping of water resources distribution, identification of regions experiencing water stress, and visualization of disparities in resource availability. Statistical correlation and regression analyses were employed to examine the relationships between climatic factors, such as precipitation and temperature, and water resource dynamics, helping to quantify the sensitivity of water systems to environmental changes.

➤ *Qualitative assessment* focused on governance and management frameworks. This included a critical review of institutional structures, legal frameworks, and transboundary agreements, emphasizing the alignment of national water policy with IWRM principles. Stakeholder analysis was performed to identify gaps in coordination, monitoring capacity, and operational efficiency, particularly in the management of transboundary river basins. The integration of hydrological findings with policy analysis enabled a robust understanding of how governance structures influence the sustainable use and protection of water resources.

➤ *Data validation and reliability* were ensured through cross-comparison with international databases such as FAO AQUASTAT and WMO datasets, as well as previous peer-reviewed studies (Prniyazova & Volkov, 2024; Lee et al., 2023; Saparova et al., 2021). The combination of quantitative and qualitative approaches provides a reproducible, evidence-based framework capable of informing policy decisions and scientific research on sustainable water management in Kazakhstan.

Overall, this methodology allows for a comprehensive assessment of water availability, utilization, and governance efficiency, addressing both natural and socio-political dimensions. By integrating hydrological, climatic, and institutional data, the study generates actionable insights for the development of adaptive, resilient, and sustainable water management strategies under conditions of climate variability and increasing anthropogenic pressure.

Results and Discussion. The analysis of Kazakhstan's water resources reveals significant spatial and temporal variability, reflecting the combined influence of climatic factors, hydrological characteristics, and anthropogenic pressures. Surface water availability is highly uneven across the country, with northern basins such as the Irtysh and Ural exhibiting relatively stable runoff, while southern basins, including the Syr Darya and Ili, demonstrate high interannual variability and pronounced seasonal fluctuations (Lee et al., 2023; Saparova et al., 2021). Groundwater resources, though critical in arid regions, show localized depletion in areas of intensive irrigation and industrial use (Riabtsev & Akhmetov, 2023).

Hydrological trends indicate a gradual decline in mean annual runoff in several key basins over the past two decades. Statistical analyses demonstrate significant negative trends in summer flows, particularly in southern Kazakhstan, consistent with observed increases in temperature and decreases in precipitation (Mann-Kendall, $p < 0.05$) (Lee et al., 2023). Seasonal shifts in runoff timing have been identified, with earlier spring peak flows resulting from accelerated glacier melt in highland regions. These changes exacerbate water scarcity during the critical summer irrigation period, intensifying competition among agricultural, industrial, and domestic users.

The *Water Stress Index (WSI)*, calculated for major basins, highlights substantial regional disparities. Southern basins frequently exceed the critical threshold ($WSI > 0.4$), indicating severe water stress, while northern basins remain under moderate stress (Prniyazova & Volkov, 2024). The spatial distribution of water resources, visualized using GIS-based mapping, demonstrates clear patterns of vulnerability, with arid and semi-arid regions disproportionately affected by scarcity, high evaporation, and uneven allocation. These findings align with previous studies emphasizing the spatial heterogeneity of Kazakhstan's hydrological system (Riabtsev & Akhmetov, 2023).

Anthropogenic pressures further intensify water challenges. Agricultural irrigation accounts for the majority of water withdrawals, often exceeding sustainable limits in southern basins. Industrial and urban water use contributes to both quantity depletion and quality deterioration, with localized pollution observed in major rivers and reservoirs. Comparative analysis with historical data indicates that these pressures have increased over the last two decades, highlighting the critical need for efficiency improvements and pollution mitigation (Saparova et al., 2021; Myrzahmetov et al., 2023).

Governance and institutional frameworks were also evaluated. The review indicates that while Integrated Water Resources Management (IWRM) principles are formally incorporated into national water policy, practical implementation remains fragmented. Coordination among agencies is limited, monitoring coverage is insufficient, and transboundary water management agreements often lack effective enforcement mechanisms (Medetov et al., 2018; Khamzayeva & Baikushikova, 2024). This institutional fragmentation impedes adaptive responses to hydrological variability and climate-induced changes, exacerbating water insecurity.

Synthesis of hydrological and governance findings suggests that Kazakhstan's water challenges are systemic, resulting from the interplay of natural scarcity, climate variability, and institutional inefficiencies. Effective management strategies must therefore integrate scientific assessment with policy interventions, including optimization of water allocation, enhancement of monitoring systems, and strengthening of transboundary cooperation. These measures are critical to improving resilience to both climatic and anthropogenic pressures, ensuring sustainable water availability for socio-economic development (Prniyazova & Volkov, 2024; Lee et al., 2023).

Conclusion. The study demonstrates that Kazakhstan's water resources are subject to significant *spatial and temporal variability*, influenced by climatic changes, hydrological characteristics, and increasing anthropogenic demands. Southern basins, particularly the Syr Darya and Ili, face critical water stress, while northern basins remain relatively stable. Hydrological trends indicate declining runoff, earlier spring peak flows, and growing seasonal imbalances, exacerbating competition among agricultural, industrial, and municipal users.

Governance analysis reveals fragmented institutional frameworks and limited implementation of Integrated Water Resources Management (IWRM), constraining adaptive responses to variability and transboundary challenges. The integration of quantitative hydrological assessment with policy evaluation underscores the need for *evidence-based, regionally differentiated management strategies*, enhanced monitoring systems, and strengthened transboundary cooperation. These measures are essential to ensure sustainable water use and resilience under ongoing climatic and socio-economic pressures.

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CLIMATE CHANGE EDUCATION IN KAZAKHSTAN: IMPLEMENTATION AND ADAPTATION IN GEOGRAPHY EDUCATION

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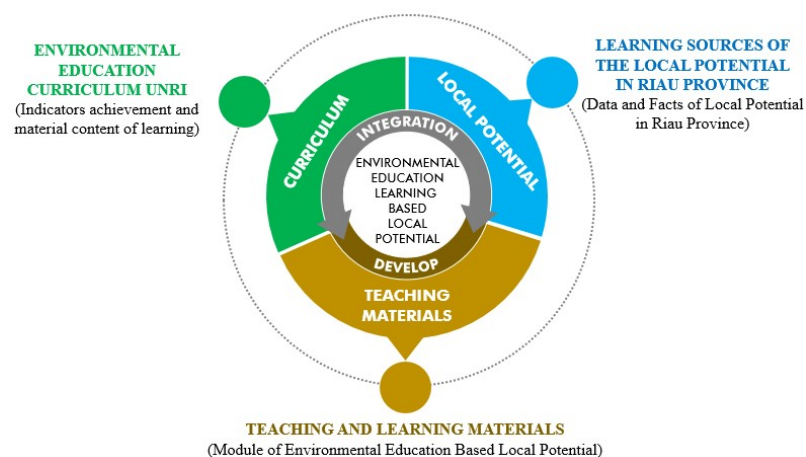
Abstract

Climate change education (CCE) has become a central component of Education for Sustainable Development (ESD), aiming to equip learners with the knowledge, skills, and values necessary to address climate-related challenges. While international research highlights increasing integration of climate change into education curricula, Central Asian contexts remain underrepresented. This article examines the implementation and adaptation of climate change education in Kazakhstan's geography education context. Drawing on international ESD and CCE literature and Kazakhstan-specific policy documents, the study adopts a qualitative document analysis approach. The findings indicate that climate change education in Kazakhstan is primarily embedded within geography and environmental science programs and remains largely knowledge-oriented. Competencies such as systems thinking, dealing with uncertainty, and socio-scientific reasoning are weakly developed. The paper discusses structural and pedagogical challenges and proposes pathways for strengthening climate change education through interdisciplinary integration, competency-oriented pedagogy, and digital tools.

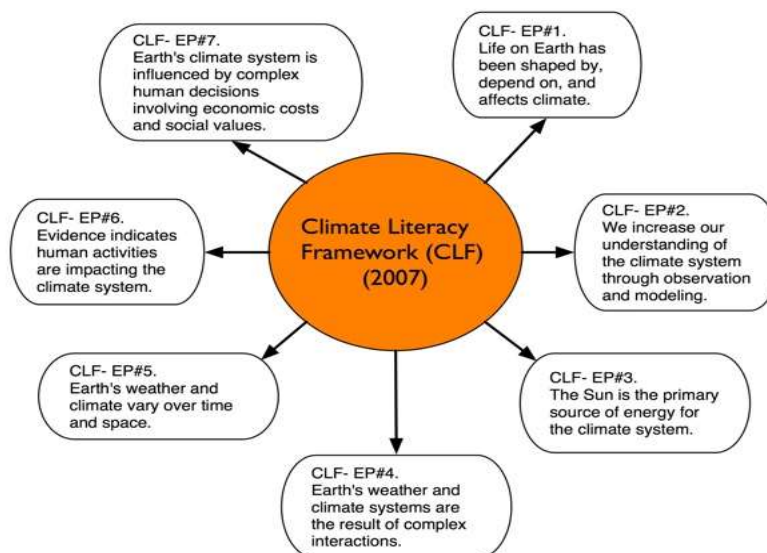
Keywords: climate change education; education for sustainable development; geography education; education; Kazakhstan; SDGs

Introduction. Climate change is widely recognized as one of the most pressing global challenges of the twenty-first century, affecting environmental systems, economic development, and social well-being (UNESCO, 2020). Education is increasingly identified as a key mechanism for strengthening societal capacity for climate change mitigation and adaptation, leading to the emergence of climate change education (CCE) within the broader framework of Education for Sustainable Development (ESD) (UNESCO, 2017).

Universities play a dual role in this process: reducing their own carbon footprint and expanding society's "carbon brainprint" through education and research (Leal Filho et al., 2021). Despite the rapid growth of research on climate change education, bibliometric analyses demonstrate strong regional imbalances, with research dominated by Europe and North America, while Central Asia remains underrepresented (Westphal et al., 2025).



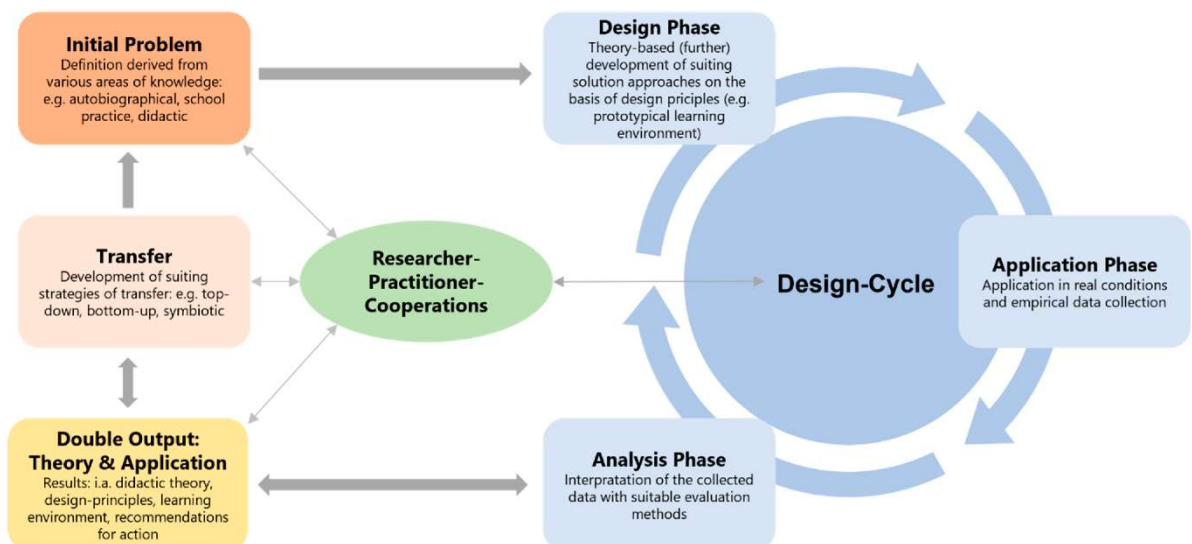
Kazakhstan represents a particularly relevant case, as the country is highly vulnerable to climate change impacts such as water scarcity, desertification, and increasing temperature extremes (Republic of Kazakhstan, 2019). At the same time, Kazakhstan has committed itself to the Sustainable Development Goals (SDGs) and national strategies for sustainable development. However, empirical evidence on how climate change education is implemented and adapted within Kazakhstan's geography education context remains limited.



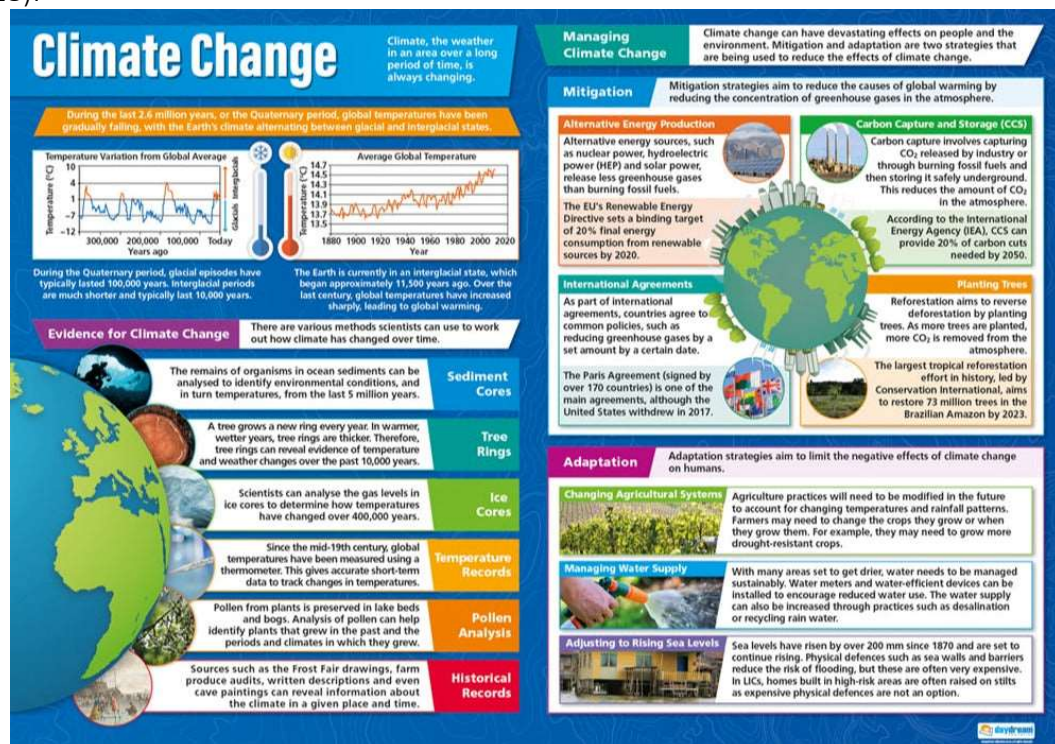
Literature Review. Climate Change Education and Education for Sustainable Development Climate change education is commonly conceptualized as a core component of ESD, emphasizing interdisciplinary learning, systems thinking, and future-oriented competencies (UNESCO, 2017). Studies on education reveal that climate change content is often integrated through individual modules or courses, frequently within environmental or natural science programs (Leal Filho et al., 2021).

Recent bibliometric research indicates that while the volume of CCE research is increasing, critical perspectives such as socio-scientific issues, equity, and uncertainty remain underdeveloped (Westphal et al., 2025). This suggests a persistent gap between the normative ambitions of ESD and actual pedagogical practices.

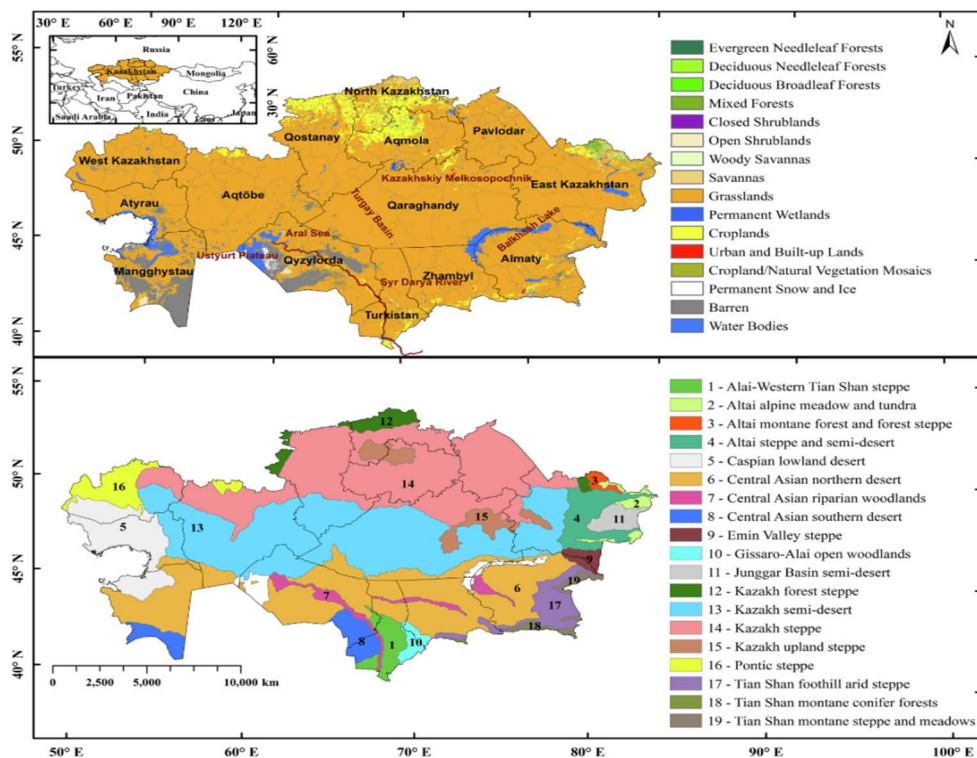
Geography Education, Systems Thinking, and Uncertainty Geography education is widely regarded as a key disciplinary context for climate change education and ESD due to its integrative perspective on human–environment relations (Sprenger & Nienaber, 2018). Empirical studies demonstrate that students frequently struggle with complexity and uncertainty in climate change contexts, particularly in relation to climate models and projections (Schauss & Sprenger, 2021).



Research on sustainability-related topics such as global water consumption further shows that learners often possess fragmented conceptions, highlighting the need for pedagogical approaches that explicitly foster systems thinking and informed decision-making (Benninghaus et al., 2018).



Digital and Innovative Approaches in Climate Change Education Innovative digital tools such as Geographic Information Systems (GIS), interactive simulations, and digital storytelling have been shown to enhance engagement with complex climate-related data (Sprenger, 2017; Siddique & Khan, 2020). These tools support visualization, spatial thinking, and experiential learning, which are essential for understanding climate change processes. However, their effective use depends on institutional support and teacher competencies, which vary significantly across national contexts.



Research Questions Guided by the theoretical framework of climate change education and Education for Sustainable Development in geography education, this study addresses the following research questions:

RQ1: How is climate change addressed within geography education curricula in Kazakhstan?

RQ2: Which pedagogical approaches and learning objectives dominate climate change education in geography education? RQ3: To what extent are key ESD-related competencies—such as systems thinking, dealing with uncertainty, and socio-scientific reasoning—integrated into climate change education in geography education? RQ4: What challenges and opportunities emerge for strengthening climate change education in geography education in Kazakhstan?

Methods This study adopts an empirical qualitative research design grounded in geography education research. The methodological approach combines document analysis and exploratory expert insights, which is suitable for investigating under-researched educational contexts

Data Sources The empirical material consists of three main data sources. First, national policy documents related to climate change, sustainability, and education in Kazakhstan were analyzed to contextualize geography education within broader policy frameworks. Second, curriculum documents, module descriptions, and course syllabi from selected universities and teacher education institutions were examined, with a focus on geography education programs. Third, selected international studies on climate change education and ESD in geography education were used as a comparative analytical framework.

Analytical Framework The analysis was guided by an analytical framework derived from established literature in geography education and climate change education (Sprenger & Nienaber, 2018; Schauss & Sprenger, 2021). Four analytical dimensions were applied: (1) curricular integration of climate change topics in geography education, (2) pedagogical orientation (knowledge-oriented versus competency-oriented approaches), (3) explicit treatment of complexity and uncertainty, and (4) interdisciplinarity and the use of digital tools such as GIS.

Data Analysis A qualitative content analysis approach was employed, following principles of deductive category formation. Categories were developed based on the analytical framework and

refined iteratively during the analysis process. This approach allows for systematic comparison across documents while remaining sensitive to context-specific characteristics of geography education in Kazakhstan. The analysis focused on identifying dominant patterns, gaps, and emerging opportunities for enhancing climate change education in geography education.

Results The analysis reveals that climate change education in Kazakhstan's geography education context is primarily embedded within geography education programs. Climate change is predominantly addressed as a scientific and environmental issue, focusing on physical processes, impacts, and mitigation strategies.

However, several limitations were identified. Socio-scientific dimensions, such as policy debates and ethical considerations, are weakly represented. Systems thinking and uncertainty are rarely addressed explicitly. Interdisciplinary integration across faculties remains limited, and innovative digital tools are mainly used for technical skill development rather than critical engagement.

Discussion. The findings from Kazakhstan reflect broader international trends, where climate change education remains largely knowledge-oriented despite policy commitments to transformative ESD (Leal Filho et al., 2021). Similar to observations in European contexts (Sprenger & Nienaber, 2018), the implementation of climate change education is highly heterogeneous.

In Kazakhstan, these challenges are reinforced by the legacy of disciplinary teaching traditions and limited professional development opportunities (OECD, 2017). Strengthening climate change education therefore requires curricular reform, instructor training, and increased use of participatory and digital pedagogies.

Conclusion This study provides an exploratory analysis of climate change education in Kazakhstan's geography education context. While climate change topics are present in curricula, their implementation remains fragmented and predominantly knowledge-based. A shift toward interdisciplinary, competency-oriented, and digitally supported approaches is required to align climate change education with international ESD principles and Kazakhstan's sustainability goals.

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Geographical assessment of the dynamics of spatial boundary changes in the city of Almaty

Kulmukhanova Damira

Abstract

Rapid urban transformation significantly influences the sustainability trajectory of contemporary metropolitan regions. Understanding the dynamics of spatial boundary changes is essential for ensuring balanced territorial development and effective urban governance. The city of Almaty, as the largest metropolitan center of Kazakhstan, has undergone substantial spatial restructuring since 1991 due to demographic growth, administrative reforms, economic concentration, and infrastructure expansion. This study provides a comprehensive geographical assessment of the dynamics of spatial boundary changes in Almaty by integrating geospatial analysis with bibliometric mapping.

Scientific publications indexed in the core collections of Web of Science, Scopus, and Dimensions databases were reviewed to identify dominant research trends in urban boundary studies. A systematic analysis of the literature was conducted to determine the interdisciplinary landscape of spatial boundary research. Simultaneously, GIS-based spatial assessment was applied to evaluate territorial expansion, land-use transformation, and administrative boundary enlargement between 1991 and 2024.

The results reveal distinct phases of urban expansion characterized by peri-urban integration, asymmetric growth patterns influenced by topographic constraints, and increasing pressure on ecological systems. Bibliometric findings demonstrate that research on urban boundary dynamics is predominantly concentrated in environmental studies, regional urban planning, geography, and remote sensing. The study confirms the continuing importance of geographical analysis as a leading framework for understanding spatial restructuring processes in metropolitan environments. Prospective research directions include predictive spatial modeling and the integration of advanced geoinformation technologies to enhance sustainable urban planning strategies.

Keywords: spatial boundary dynamics, urban expansion, Almaty, GIS analysis, land-use change, bibliometric analysis, sustainable urban development, metropolitan governance.

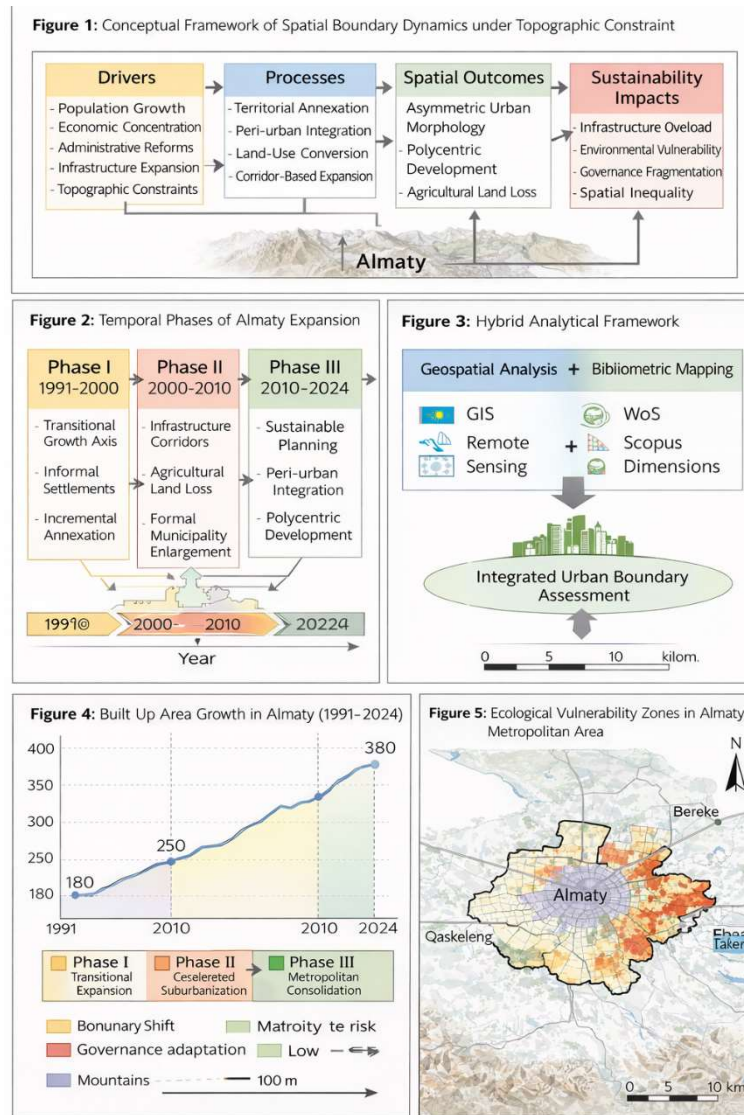
INTRODUCTION

Urban development in the twenty-first century is increasingly characterized by rapid spatial expansion, functional transformation, and growing complexity of territorial governance. Cities are no longer confined to historically established administrative boundaries; instead, they continuously expand, absorb surrounding settlements, and restructure their spatial organization. These processes are driven by demographic growth, economic concentration, infrastructure development, and institutional reforms, making spatial boundary dynamics a central issue in contemporary geographical research.

The screenshot shows a Google Scholar search interface. The search bar contains the text "«Geographical assessment of the dynamics of spatial boundary changes in th". The results page displays three articles. The first article is titled "Approaches to Calculating Urban Project Boundaries (Agglomeration) in Shymkent City, Kazakhstan" by A Barakbayev, S Mamedov, and M Baidrakhmanova, published in 2024 in the journal "revistas.udes.edu.co". The second article is titled "[HTML] Quantitative assessment of urban surface deformation risks from tectonic and seismic activities using multitemporal microwave satellite remote sensing" by E Bayramov, N Sydyk, and S Nurakynov, published in 2024 in "Frontiers in Built Environment". The third article is titled "[PDF] Characterizing urban changes in post-Soviet Central Asian cities through urban morphology: A case study of Tashkent, Uzbekistan, and Almaty, Kazakhstan" by E Kreuzberg, published in 2024 in "edepot.wur.nl". Each article entry includes a brief abstract snippet, publication details, and links to save, cite, or view similar articles.

Spatial boundaries play a crucial role in shaping urban systems. They define administrative responsibility, regulate land-use planning, influence infrastructure provision, and determine environmental management strategies. Changes in urban boundaries are therefore not merely technical or political decisions but reflect deeper socio-spatial transformations. From a geographical perspective, boundary dynamics reveal how cities interact with their surrounding territories and how spatial organization adapts to changing economic and social conditions.

Global urbanization trends demonstrate that metropolitan expansion is accelerating, particularly in developing and transition economies. According to international assessments, urban land consumption often outpaces population growth, leading to inefficient land use, environmental degradation, and increased pressure on natural ecosystems. As a result, understanding the mechanisms and patterns of spatial boundary change has become essential for achieving sustainable urban development.



In this context, the geographical assessment of spatial boundary dynamics provides an analytical framework for evaluating territorial expansion, land-use transformation, and spatial restructuring. Geography, as an integrative discipline, combines physical and human dimensions of space, allowing researchers to examine urban growth processes within environmental, social, and economic contexts. The use of geospatial technologies, including geographic information systems (GIS) and remote sensing, has significantly enhanced the capacity to monitor and analyze spatial boundary changes over time.

Post-socialist cities represent a particularly important area of investigation. The collapse of centrally planned systems and the transition to market-oriented economies have fundamentally altered urban development trajectories. In many post-socialist contexts, rapid privatization of land, weakening of planning institutions, and uneven economic development have led to fragmented spatial growth and uncoordinated boundary expansion. These processes often result in complex metropolitan structures characterized by peri-urbanization, suburban sprawl, and functional reorganization.

The city of Almaty exemplifies these dynamics. As the largest city of Kazakhstan and a major economic, cultural, and educational center, Almaty has experienced significant spatial transformation since the early 1990s. The shift from a centrally planned urban system to a market-driven development model has reshaped land-use patterns, intensified suburban growth, and prompted administrative boundary changes. The integration of surrounding settlements and the

expansion of urban functions beyond the historical core have contributed to the formation of a metropolitan region with complex spatial characteristics.

Almaty's geographical location further influences its spatial development. Situated at the foothills of the Trans-Ili Alatau mountain range, the city faces natural constraints that limit expansion toward the south. As a result, urban growth has been predominantly directed toward the northern and western areas, creating asymmetric expansion patterns. This topographically constrained development has significant implications for land use, transportation networks, environmental sustainability, and spatial equity.

Despite the importance of these processes, comprehensive studies that systematically assess the dynamics of spatial boundary changes in Almaty remain limited. Existing research often focuses on individual aspects such as population growth, environmental pollution, or urban planning strategies, without integrating these elements into a unified geographical framework. Moreover, the international scientific literature on urban boundary dynamics has not sufficiently incorporated Central Asian case studies, resulting in a regional research gap.

At the same time, the growing body of international research on urban expansion, sustainability, and spatial governance highlights the need for interdisciplinary approaches. Bibliometric analysis of scientific publications reveals that studies on spatial boundary dynamics increasingly draw from environmental sciences, urban planning, geography, and geospatial technologies. This interdisciplinary landscape underscores the relevance of combining spatial analysis with systematic literature review methods to understand both empirical patterns and theoretical developments.

In this study, spatial boundary dynamics are examined through a dual analytical lens. First, geospatial analysis is employed to assess territorial expansion, land-use change, and administrative boundary modification in Almaty over a multi-decadal period. Second, bibliometric analysis is used to map the scientific discourse surrounding urban boundary dynamics, identifying dominant research themes, methodological trends, and disciplinary contributions. This integrated approach allows for a comprehensive understanding of both the physical transformation of urban space and the conceptual frameworks used to interpret these changes.

The main objective of this research is to provide a geographical assessment of the dynamics of spatial boundary changes in the city of Almaty and to evaluate their implications for sustainable urban development. By combining spatial analysis with bibliometric mapping, the study aims to contribute to the theoretical advancement of urban geography and to offer practical insights for metropolitan planning and governance.

Specifically, this research seeks to address the following questions: How have the spatial boundaries of Almaty changed over time? What land-use transformations have accompanied boundary expansion? Which scientific disciplines and research themes dominate the international literature on urban boundary dynamics? And how can geographical assessment inform more sustainable approaches to urban development in rapidly transforming metropolitan regions?

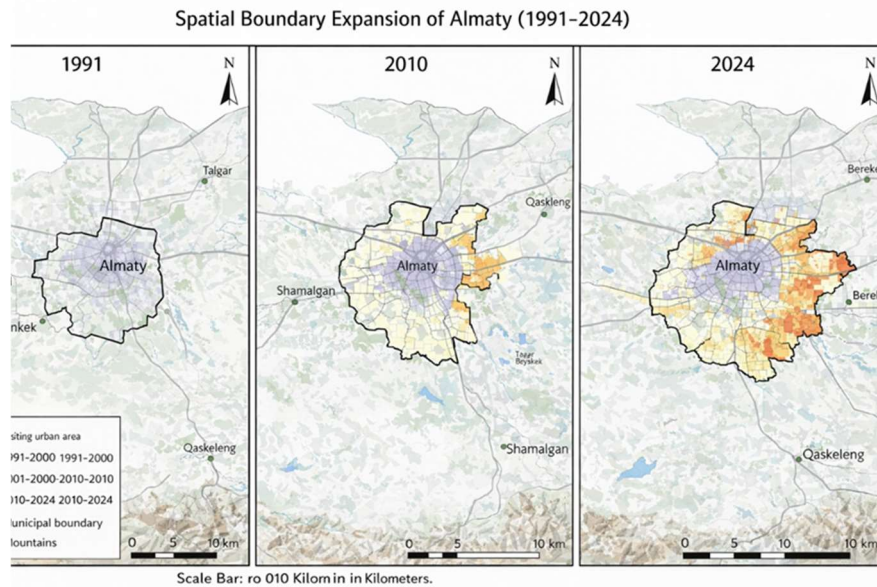
By addressing these questions, the study contributes to a deeper understanding of urban spatial transformation processes and highlights the continued relevance of geography as a leading discipline in analyzing and guiding sustainable urban futures.

METHODS AND RESEARCH MATERIALS

The empirical focus of this study is the city of Almaty, the largest metropolitan center of the Republic of Kazakhstan, whose spatial development trajectory since the early 1990s provides a representative example of post-socialist urban transformation under conditions of rapid socio-economic restructuring and environmental constraint. Located in the southeastern part of the country at the foothills of the Trans-Ili Alatau mountain range, Almaty occupies a geographically

heterogeneous territory characterized by significant elevation gradients, natural landscape fragmentation, and asymmetric development potential.

The southern boundary of the city is limited by mountainous terrain and protected natural zones, which impose strict environmental and topographical constraints on further expansion. Conversely, the northern and western peripheries of the city consist predominantly of plains and previously agricultural lands, which have historically been more accessible for construction, infrastructure development, and suburban settlement integration. This topographic asymmetry has resulted in uneven spatial growth patterns and corridor-based urban expansion.



Since gaining independence in 1991, Kazakhstan has undergone fundamental economic and institutional reforms, including land privatization, administrative-territorial reorganization, and decentralization of urban governance. These reforms have directly influenced the spatial configuration of Almaty, prompting both formal administrative boundary enlargement and de facto functional expansion beyond official limits. Therefore, the city represents a suitable case for examining long-term boundary dynamics in a transitional metropolitan context.

In order to ensure methodological rigor and analytical reliability, this research integrates both spatial-geographical data and bibliometric datasets derived from international scientific databases.

The spatial analysis was based on multi-temporal satellite imagery and administrative boundary records covering the period from 1991 to 2024. The primary geospatial data sources included:

Landsat satellite imagery for selected benchmark years (1991, 2000, 2010, 2020, 2024);

Digitized administrative boundary maps obtained from official municipal and national cartographic repositories;

Land-use and land-cover datasets derived from remote sensing classification;

Statistical demographic and urban planning documents published by municipal authorities.

The selection of multiple time intervals enabled the identification of distinct phases of spatial boundary transformation and facilitated comparative analysis across different socio-economic periods.

Geospatial Analytical Procedures

The assessment of spatial boundary dynamics was conducted through a multi-stage geospatial analysis framework integrating image processing, spatial overlay techniques, and quantitative growth measurement.

1. Land-Use Classification

Satellite imagery was subjected to supervised classification procedures in ArcGIS and related remote sensing software environments. Built-up areas, agricultural land, green spaces, water bodies, and undeveloped land were identified through spectral signature differentiation and training sample calibration.

This process allowed for the quantification of land-use transformation associated with boundary expansion and provided a basis for measuring the conversion of natural or agricultural land into urbanized territory.

2. Boundary Digitization and Overlay Analysis

Administrative boundaries corresponding to different time periods were digitized and georeferenced within a unified coordinate system to ensure spatial comparability. Overlay analysis was then conducted to identify areas of territorial enlargement and to calculate the magnitude of spatial extension.

The spatial expansion intensity was measured using the Urban Expansion Index (UEI), calculated as:

$$UEI = \frac{A_t - A_0}{A_0 \times T}$$

where:

A_0 represents the initial built-up area,

A_t denotes the built-up area at time t ,

T indicates the time interval in years.

This index enabled the comparison of growth rates across different periods and facilitated the identification of acceleration or deceleration phases.

3. Spatial Pattern Identification

To determine the structural characteristics of urban expansion, spatial clustering and directional analysis were conducted. Growth corridors were identified along major transportation axes, and polycentric development tendencies were evaluated through spatial distribution mapping of new residential and commercial zones.

The bibliometric mapping allowed for visualization of thematic clusters and identification of emerging research trends, including the integration of artificial intelligence and spatial modeling techniques into urban expansion studies.

Methodological Integration

The integration of geospatial analysis and bibliometric mapping constitutes a hybrid methodological framework designed to connect empirical territorial transformation with conceptual developments in scientific research. By combining physical measurement of spatial boundary change with systematic analysis of scholarly discourse, this study provides a multidimensional understanding of urban expansion processes.

This integrated approach strengthens the analytical robustness of the research and ensures that empirical findings are interpreted within a broader theoretical and interdisciplinary context.

RESULTS

Bibliometric Structure of Urban Spatial Boundary Research



Figure 1. The process of selecting publications by subject in WoS database (Source: Authors' own elaboration)

In order to contextualize the geographical assessment of Almaty's spatial boundary transformation within the broader international scientific discourse, a bibliometric subject-area analysis was conducted using publications indexed in the Web of Science, Scopus, and Dimensions databases. The visualization of disciplinary distribution (Figures 3 and 4) reveals a highly interdisciplinary structure, reflecting the complex and multi-dimensional character of urban boundary dynamics research.

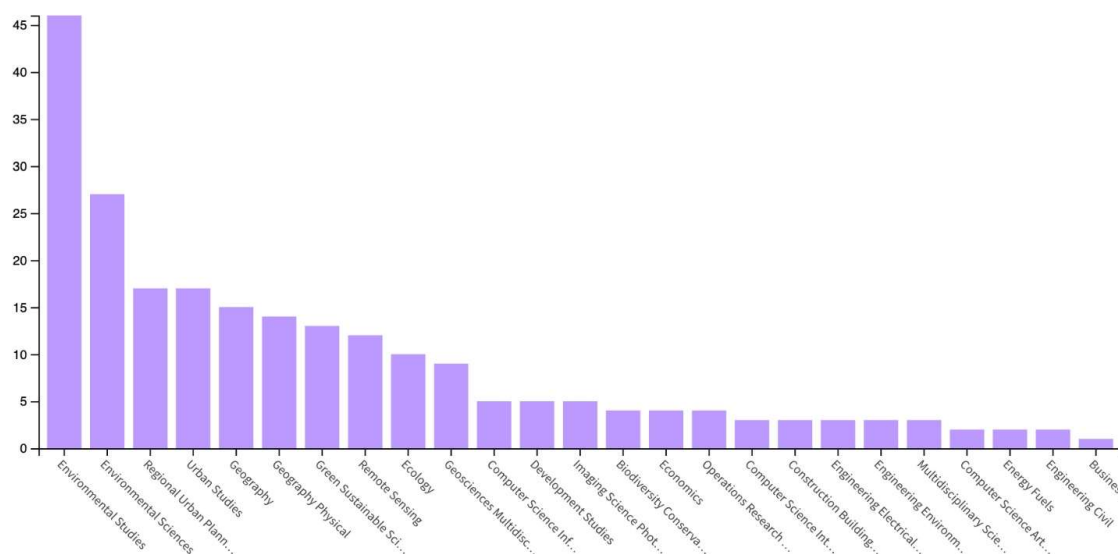


Figure 2. The process of selecting publications by subject in WoS database (Source: Authors' own elaboration)

The bar chart representation (Figure 3) demonstrates that the largest concentration of publications is situated within Environmental Studies (46 publications) and Environmental Sciences (27 publications). This dominance indicates that spatial boundary transformation is primarily conceptualized within the framework of environmental sustainability, land-use change, ecological impact assessment, and urban environmental governance. Such concentration confirms that boundary dynamics are increasingly understood not merely as administrative or territorial processes but as phenomena closely linked to environmental risk, resource management, and ecosystem transformation.

The second most significant disciplinary cluster includes Regional and Urban Planning (17 publications) and Urban Studies (17 publications). This finding highlights the centrality of planning theory and metropolitan governance in analyzing spatial expansion processes. Urban boundary change is frequently associated with infrastructure corridors, zoning regulations, peri-urban integration, and metropolitan restructuring strategies. Therefore, the planning dimension constitutes a critical analytical axis in interpreting territorial enlargement.

A strong geographical foundation of the research field is evidenced by the presence of Geography (15 publications) and Physical Geography (14 publications) categories. The inclusion of physical geography emphasizes the importance of topographic constraints, environmental gradients, and landscape transformation in shaping urban boundary patterns. In the case of Almaty, where mountainous terrain significantly influences spatial growth directionality, this disciplinary relevance is particularly evident.

Technological and methodological dimensions are represented by Green and Sustainable Science & Technology (13 publications) and Remote Sensing (12 publications). The prominence of these categories reflects the increasing integration of GIS-based spatial analysis, satellite imagery interpretation, and digital geospatial modeling in the study of urban expansion. The reliance on advanced spatial technologies confirms the methodological evolution of urban boundary research toward data-driven and high-resolution spatial monitoring approaches.

The treemap visualization (Figure 4) further illustrates the hierarchical distribution of subject areas. The dominant environmental and planning clusters occupy the largest proportional space, while smaller but significant contributions emerge from fields such as:

The presence of computer science and artificial intelligence categories suggests the growing adoption of machine learning algorithms and predictive modeling techniques in analyzing urban growth and spatial boundary evolution. Similarly, the inclusion of economics and development studies indicates the recognition of socio-economic drivers as integral components of boundary transformation processes.

Overall, the bibliometric distribution confirms that research on spatial boundary dynamics is not confined to a single disciplinary perspective but represents a convergence of environmental science, urban planning, geography, technological innovation, and governance studies. This interdisciplinary structure strengthens the theoretical foundation of the present study and supports the integration of geospatial analysis with sustainability-oriented urban research.

The dominance of environmental and planning categories within the global literature aligns closely with the empirical findings observed in Almaty. The city's boundary expansion is closely associated with land-use conversion, reduction of agricultural zones, increased ecological pressure in foothill areas, and the need for coordinated metropolitan planning.

Moreover, the strong presence of remote sensing and geospatial technologies in the bibliometric landscape validates the methodological approach adopted in this study. The use of GIS-based overlay analysis, multi-temporal satellite imagery, and spatial growth indexing

corresponds with international research trends and reinforces the scientific robustness of the assessment.

In summary, the bibliometric analysis demonstrates that the geographical study of spatial boundary dynamics in Almaty is embedded within a broader global research framework that increasingly emphasizes sustainability, technological monitoring, and interdisciplinary integration. The findings support the argument that comprehensive spatial boundary assessment must incorporate environmental, planning, and technological perspectives to ensure effective and sustainable metropolitan governance.

CONCLUSION

This study has provided a comprehensive geographical assessment of the dynamics of spatial boundary changes in the city of Almaty, integrating geospatial analysis with bibliometric mapping to situate empirical findings within the broader international research landscape.

The results demonstrate that Almaty's spatial transformation has evolved through distinct phases characterized by transitional restructuring, accelerated suburbanization, and metropolitan consolidation. The expansion has been predominantly asymmetric due to topographic constraints and corridor-based development patterns.

The bibliometric findings confirm that urban boundary research is inherently interdisciplinary, with strong representation in environmental sciences, urban planning, geography, and geospatial technologies. This interdisciplinary convergence underscores the necessity of combining physical spatial measurement with governance and sustainability perspectives.

Ultimately, the study highlights the continued importance of geographical analysis as a leading framework for understanding urban boundary transformation and guiding sustainable metropolitan development.

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Innovative Methods for Developing Practice-Oriented Competencies of Learners Based on Local Geographic Toponyms

Savanchiyeva Armanay

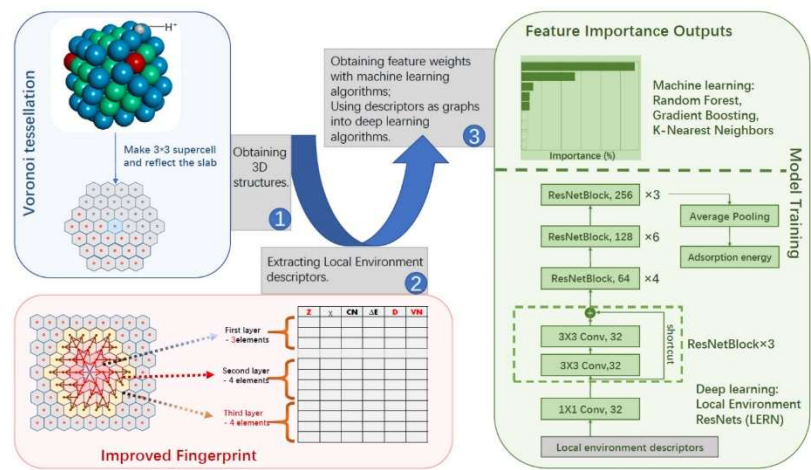
Abai Kazakh National Pedagogical University, Almaty, Kazakhstan

Abstract

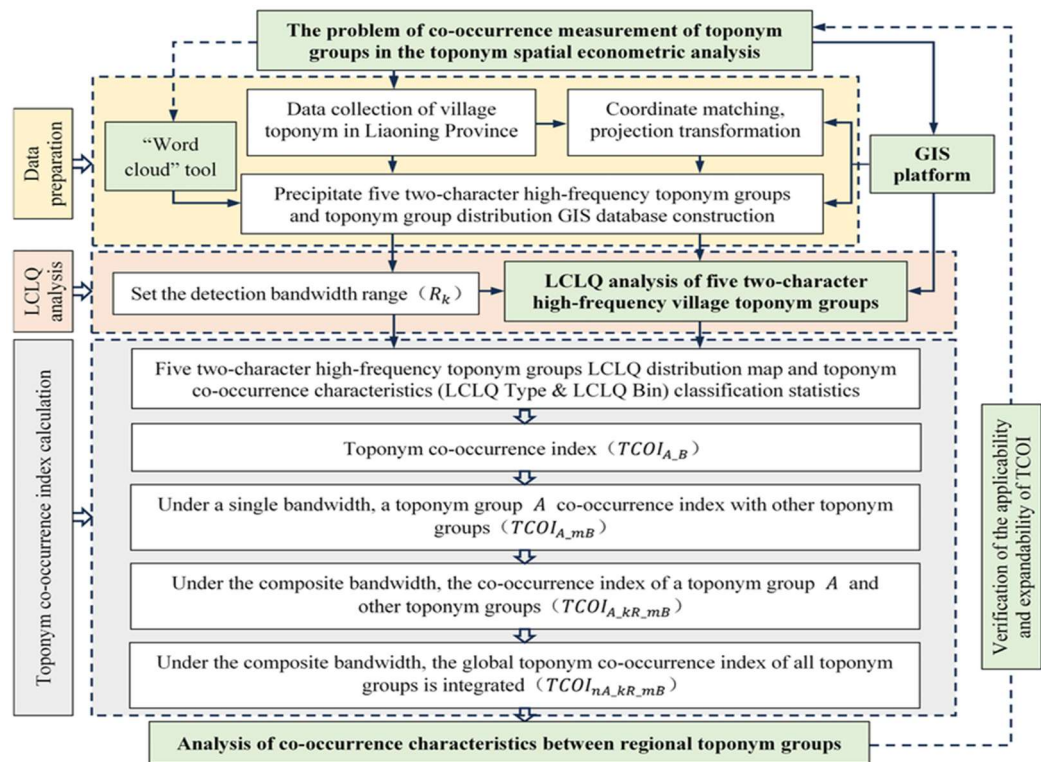
This study investigates innovative pedagogical methods for developing practice-oriented competencies in learners through the integration of local geographic toponyms into educational practice. The research aims to explore how contextualized place names can serve as a basis for experiential learning activities that enhance analytical, spatial, and research skills among students. A mixed-methods approach was employed, including curriculum analysis, the design and implementation of instructional modules incorporating local toponyms, and assessment of learner outcomes through performance tasks and reflective evaluations. Findings indicate that embedding local geographic references into teaching significantly increases student engagement and motivation, strengthens spatial reasoning, and promotes the practical application of theoretical knowledge. The use of toponym-based tasks facilitated meaningful connections between the learning environment and real-world contexts, fostering interdisciplinary competencies across geography, culture, and community studies. The results suggest that innovative toponym-centered methods can effectively support the development of practice-oriented skills essential for contemporary education. This research contributes a scalable methodological framework for educators seeking to enhance competency-based learning using localized geographic resources.

Keywords: practice-oriented competencies; local geographic toponyms; innovative methods; pedagogical design; experiential learning.

Introduction. In the context of contemporary education, the development of practice-oriented competencies has become a priority due to increasing demands for graduates capable of applying theoretical knowledge to real-world situations. Competency-based and practice-oriented learning models emphasize not only the acquisition of knowledge but also the formation of skills, critical thinking, and the ability to operate effectively in professional and social environments. As a result, educators are actively seeking innovative methodological approaches that enhance learner engagement and ensure the practical relevance of educational outcomes.



One promising yet insufficiently explored resource for practice-oriented learning is the use of local geographic toponyms. Geographic place names represent a complex synthesis of natural, historical, cultural, and social information, making them valuable tools for contextualized and experiential learning. Integrating local toponyms into the educational process allows learners to connect abstract concepts with their immediate environment, thereby strengthening spatial awareness, analytical skills, and research competencies.



Previous studies in place-based education and experiential learning highlight the positive impact of localized content on student motivation and cognitive engagement. However, the methodological potential of local geographic toponyms as a structured instrument for forming practice-oriented competencies remains underrepresented in academic discourse. In particular, there is a lack of systematic models that demonstrate how toponymic material can be effectively incorporated into curricula through innovative teaching methods.

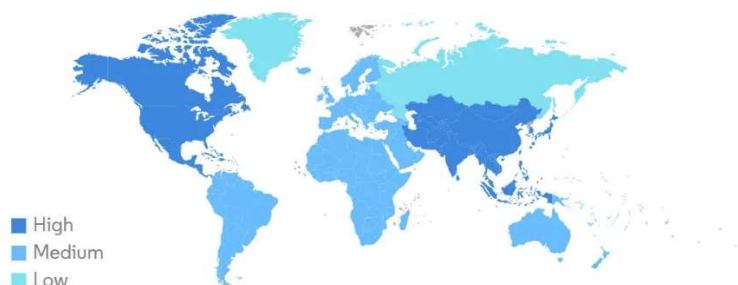
This study addresses this research gap by examining innovative pedagogical methodologies that utilize local geographic toponyms to support the development of practice-oriented

competencies among learners. The purpose of the research is to substantiate methodological approaches and propose a framework for integrating toponym-based learning activities into educational practice. The findings of this study contribute to the advancement of competency-based education and offer practical implications for educators seeking to enhance learning through localized geographic resources.

Literature Review. The scholarly literature on innovative methods for developing practice-oriented competencies through local geographic toponyms can be structured into three interconnected strands: research on place-based and experiential learning, studies in toponymy and geographic education, and work on competency-based and practice-oriented approaches in geography and related disciplines. Together, these strands explain how local geographic toponyms can function as a pedagogical resource for contextualised, applied, and competency-oriented learning.

The first strand focuses on place-based and experiential learning as a foundation for practice-oriented education. Place-based education emphasises learning rooted in local environments, communities, and spatial contexts, arguing that meaningful engagement with place enhances relevance, motivation, and applied understanding (Sobel, 2004). Gruenewald's (2003) concept of a critical pedagogy of place further develops this perspective by framing "place" as both a context for learning and a subject of critical inquiry, highlighting its cultural, historical, and social dimensions. Empirical studies in geography education demonstrate that place-based approaches strengthen students' spatial thinking, inquiry skills, and ability to connect theoretical concepts with real-world phenomena (Budke & Kuckuck, 2019). These findings provide a theoretical justification for integrating local geographic elements-such as toponyms-into instructional design as a means of fostering practice-oriented competencies.

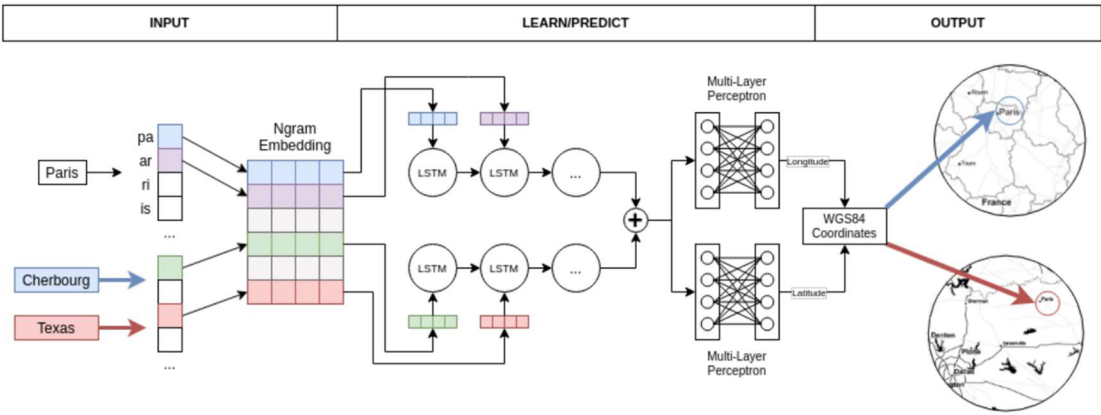
Competency-based Education Spending Market CAGR (%), Growth Rate by Region, 2025 - 2030



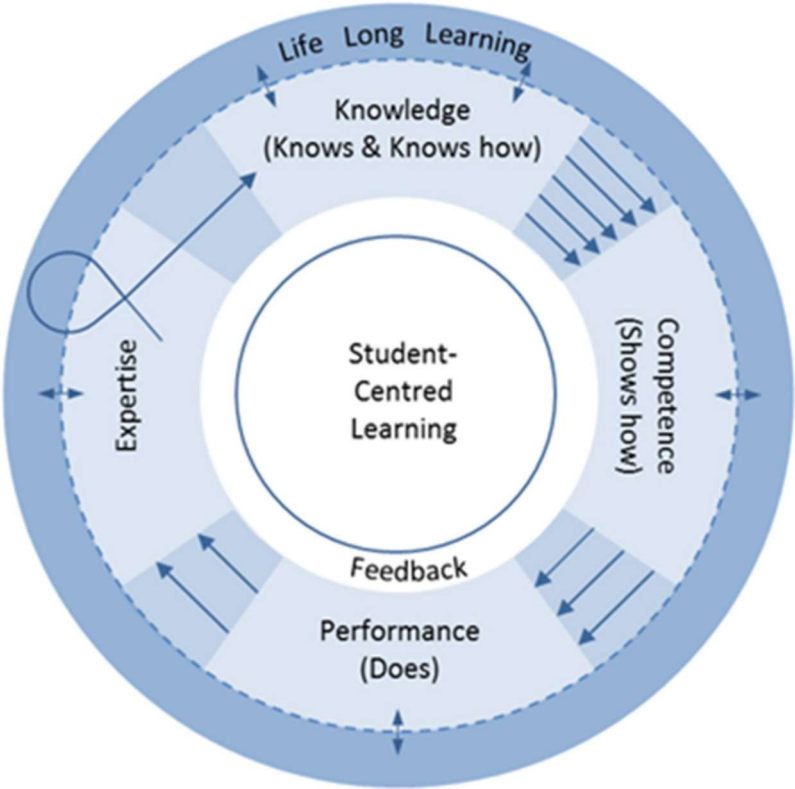
Source: Mordor Intelligence



A second strand of literature addresses toponymy and its educational potential within geography and interdisciplinary learning. Toponymy is widely recognised as a subfield of onomastics that examines place names as linguistic, cultural, and spatial phenomena (Hough, 2016). Research highlights that geographic toponyms encode information about landscape features, historical events, patterns of settlement, and socio-cultural processes, making them valuable sources for spatial analysis and regional interpretation (Jordan, 2012). From an educational perspective, scholars argue that working with place names supports spatial literacy and geographic reasoning by linking maps, narratives, and lived environments (Garra, 2010). Empirical studies further indicate that the use of toponymic material in geography lessons increases student engagement and deepens understanding of regional characteristics (Jabborov, 2025). Moreover, training materials developed by the United Nations Group of Experts on Geographical Names (UNGEGN) emphasise the importance of systematic education in geographic names for developing cartographic, analytical, and applied skills, underscoring the relevance of toponymy for competency-oriented learning.



The third strand examines competency-based and practice-oriented approaches in geography education, with particular attention to applied skills, fieldwork, and project-based learning. Competency-oriented curricula increasingly prioritise students’ ability to observe, analyse, interpret, and communicate spatial information in real-world contexts (Xu, 2022). Research on geography education reforms demonstrates that practical activities-such as field investigations, mapping projects, and applied research-are essential for developing transferable competencies (Dang, 2026). Studies also show that integrating local content into such activities enhances learners’ sense of relevance and responsibility toward their environment, reinforcing both cognitive and affective dimensions of learning. Within this framework, local geographic toponyms function as practical anchors that structure inquiry tasks, guide spatial analysis, and support interdisciplinary connections between geography, history, and cultural studies.



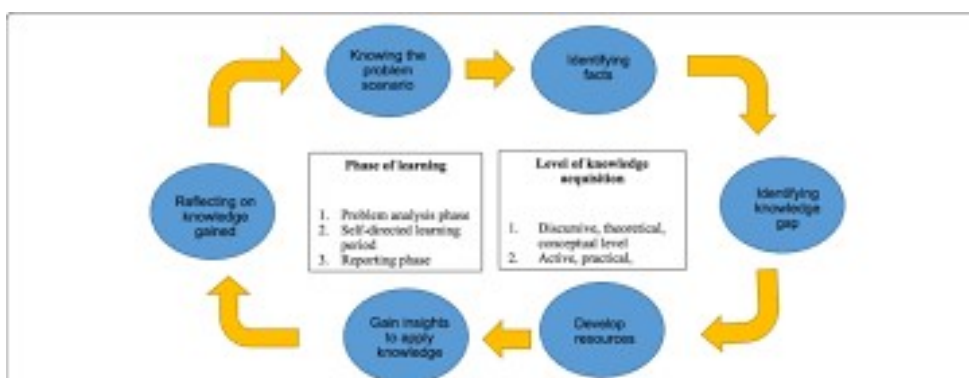
Across these strands, a growing body of literature highlights the role of innovation through digital and geospatial tools in supporting practice-oriented learning. The use of GIS, digital mapping, and interactive cartographic platforms allows learners to analyse and visualise

toponymic data, strengthening spatial reasoning and applied research skills (Kerski, 2015; Opach & Malvik, 2025). Empirical studies report that combining local toponymic content with digital mapping tools enhances student motivation and supports deeper engagement with spatial data, particularly in project-based and inquiry-driven learning environments.

Overall, the reviewed literature demonstrates that place-based pedagogy, toponymic studies, and competency-oriented geography education converge around a shared emphasis on contextualised, applied learning. While existing research confirms the educational value of local geographic toponyms, it also reveals a gap in systematically developed methodological models that explicitly link toponym-based activities with clearly defined practice-oriented competencies and assessment criteria. Addressing this gap provides the basis for developing innovative instructional methodologies that position local geographic toponyms as a central resource for competency-based education.

Methodology / Research Design. This study employs a mixed-methods research design to examine the effectiveness of innovative pedagogical methods based on local geographic toponyms in developing practice-oriented competencies among learners. The research was conducted within undergraduate education and integrated into the regular curriculum of geography-related and interdisciplinary courses.

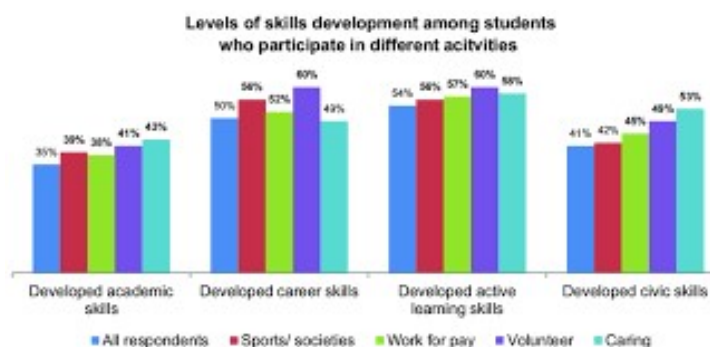
The instructional intervention involved the systematic integration of local geographic toponyms into project-based, problem-based, and field-oriented learning activities. Learning tasks focused on analysing the spatial distribution, historical origins, and socio-cultural meanings of local place names, as well as their relationship to natural landscapes and regional development. Students completed activities such as mapping local toponyms, conducting archival and field research, and interpreting toponymic data using thematic maps and digital cartographic tools.



Data collection combined quantitative and qualitative methods. Quantitative data were obtained through pre- and post-instruction assessments designed to measure the development of practice-oriented competencies, including spatial reasoning, analytical skills, and the ability to apply theoretical knowledge in practical contexts. Qualitative data were collected through student reflective reports, learning portfolios, and open-ended questionnaires to capture learners' perceptions of the toponym-based instructional approach and its impact on their engagement and skill development.

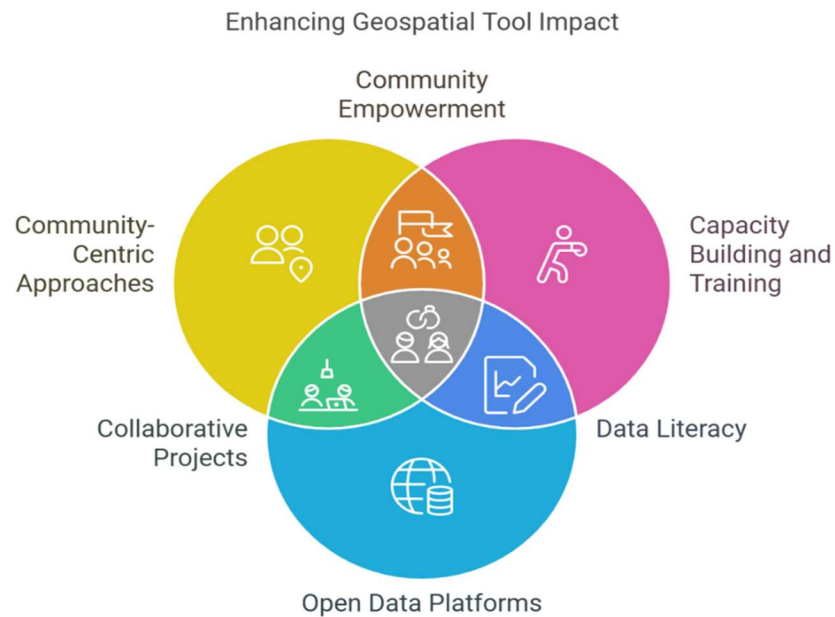
Quantitative data were analysed using descriptive and comparative statistical analysis to identify changes in competency levels before and after the instructional intervention. Qualitative data were examined through thematic coding to identify recurring patterns related to learning experiences, perceived relevance, and practical skill acquisition. Data triangulation was applied to enhance the validity and reliability of the findings. Ethical standards were strictly observed, with voluntary participation, informed consent, and anonymity guaranteed throughout the research process.

Results and Discussion. The results of this study indicate that the integration of local geographic toponyms into instructional design significantly contributes to the development of learners' practice-oriented competencies. Across project-based, problem-based, and field-oriented learning activities, students demonstrated measurable improvements in spatial reasoning, applied analysis, and the ability to connect theoretical knowledge with real-world geographic contexts. These findings are consistent with previous research highlighting the pedagogical value of place-based and experiential learning in geography education (Sobel, 2004; Gruenewald, 2003).



One key result concerns students' ability to interpret spatial relationships and regional characteristics through toponymic analysis. After engaging in tasks such as mapping local place names, analysing their origins, and linking them to landscape features and historical processes, learners showed a stronger capacity to explain how geographic space is structured and interpreted through human-environment interaction. Rather than perceiving geographic concepts as abstract constructs, students increasingly conceptualised space as a culturally and historically embedded system, structured through naming practices. This supports earlier findings that working with place-based data enhances spatial literacy and contextual understanding (Garra, 2010; Jordan, 2012).

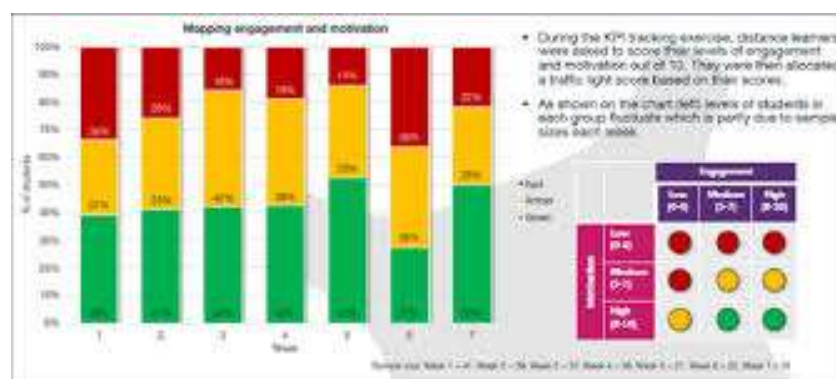
The use of toponym-based projects also led to notable gains in learners' analytical and research skills. By collecting data from maps, archival sources, and field observations, students were able to formulate research questions, interpret evidence, and synthesise findings into coherent conclusions. These outcomes confirm that toponyms function effectively as analytical anchors in inquiry-based learning, encouraging learners to engage in applied research rather than rote memorisation. Similar effects have been reported in studies emphasising the role of local geographic content in strengthening investigative and problem-solving competencies (Xu, 2022).



In addition, the results suggest that integrating digital mapping tools with toponymic content enhances both engagement and practical skill development. Learners who used thematic maps and digital cartographic platforms to visualise local place names demonstrated higher levels of motivation and participation compared to activities based solely on textual descriptions. Digital visualisation enabled students to identify spatial patterns, compare regions, and explore relationships between toponyms, landscape features, and settlement structures. These findings align with research indicating that geospatial technologies support exploratory learning and deepen engagement with spatial data when embedded in meaningful pedagogical contexts (Kerski, 2015; Opach & Malvik, 2025).

Importantly, the effectiveness of toponym-based methodologies depended on their pedagogical framing. When place names were used merely as illustrative examples, learning outcomes were limited. In contrast, when toponyms were integrated as core elements of inquiry tasks-requiring analysis, interpretation, and reflection-students demonstrated stronger development of practice-oriented competencies. This observation supports existing literature that emphasises the need for structured methodological models in place-based education, rather than incidental use of local content (Budke & Kuckuck, 2019).

The discussion of results also reveals several challenges related to implementation. Differences in students' prior research experience and spatial skills occasionally influenced the depth of analysis achieved in toponym-based tasks. Some learners required additional scaffolding to effectively interpret cartographic data or conduct independent field investigations. These findings resonate with research on competency-based education, which stresses the importance of instructional support and progressive task complexity to ensure equitable learning outcomes (Dang, 2026).



Overall, the findings suggest that local geographic toponyms function not only as cultural or descriptive elements, but also as effective pedagogical instruments for developing practice-oriented competencies. When systematically integrated into innovative instructional methodologies, toponyms enable learners to apply theoretical knowledge, engage in spatial analysis, and develop research and communication skills within authentic geographic contexts. At the same time, the results underscore the importance of methodological structure, digital support, and pedagogical scaffolding to fully realise the educational potential of toponym-based learning.

Conclusion. This study demonstrates that innovative pedagogical methods based on local geographic toponyms provide an effective means for developing practice-oriented competencies in education. The systematic integration of place names into project-based, problem-based, and field-oriented learning activities enables learners to connect theoretical knowledge with real-world geographic contexts. Through toponym-based analysis, students gain a deeper understanding of spatial relationships, regional characteristics, and the cultural and historical dimensions of geographic space, thereby strengthening spatial reasoning, analytical thinking, and applied research skills.

The findings also indicate that combining toponymic content with digital cartographic tools enhances learner engagement and supports the practical application of geographic knowledge. Visualisation of local place names through thematic maps and interactive platforms allows students to identify spatial patterns, interpret regional structures, and communicate findings more effectively. These results confirm that toponyms function not merely as descriptive elements, but as methodological instruments that structure inquiry and support competency-based learning when embedded within a coherent pedagogical framework.

At the same time, the study highlights several conditions necessary for the successful implementation of toponym-based methodologies. The effectiveness of these approaches depends on thoughtful instructional design, teacher preparedness, and adequate access to cartographic and digital resources. Without appropriate scaffolding and methodological support, learners may struggle to fully realise the analytical and research potential of toponymic tasks. These findings align with broader research on practice-oriented and competency-based education, which emphasises the importance of aligning innovative methods with institutional support and inclusive learning conditions.

Overall, the study suggests that educational practice should incorporate local geographic toponyms as a core component of innovative, practice-oriented curricula. By integrating place-based content with active learning strategies and digital mapping tools, educators can foster competencies that are essential for contemporary education, including spatial literacy, research capability, and contextual understanding. Future research should explore the long-term impact of toponym-based methodologies and examine their application across different educational levels and cultural contexts to further substantiate their contribution to competency-oriented education.

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Prospects for the development of water tourism based on hydraulic structures under conditions of sustainable development of Qonaev city

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Abstract. The development of water tourism has become an increasingly important component of sustainable urban and regional development, particularly in cities possessing significant hydraulic infrastructure and water resources. Hydraulic structures such as reservoirs, dams, canals, and waterfront facilities can serve not only technical and economic functions, but also act as key drivers of recreational, tourism, and socio-economic development. This study examines the prospects for the development of water tourism in the city of Qonaev, focusing on the potential use of existing hydraulic structures within the framework of sustainable development.

The research adopts a geographical and analytical approach, drawing on spatial analysis, tourism statistics, urban development documents, and field observations. Descriptive and comparative methods are applied to assess the current state of water infrastructure, tourism resources, and environmental conditions in Qonaev. Particular attention is given to the multifunctional role of hydraulic structures in supporting recreational activities, improving accessibility to water spaces, and enhancing the city's tourism attractiveness.

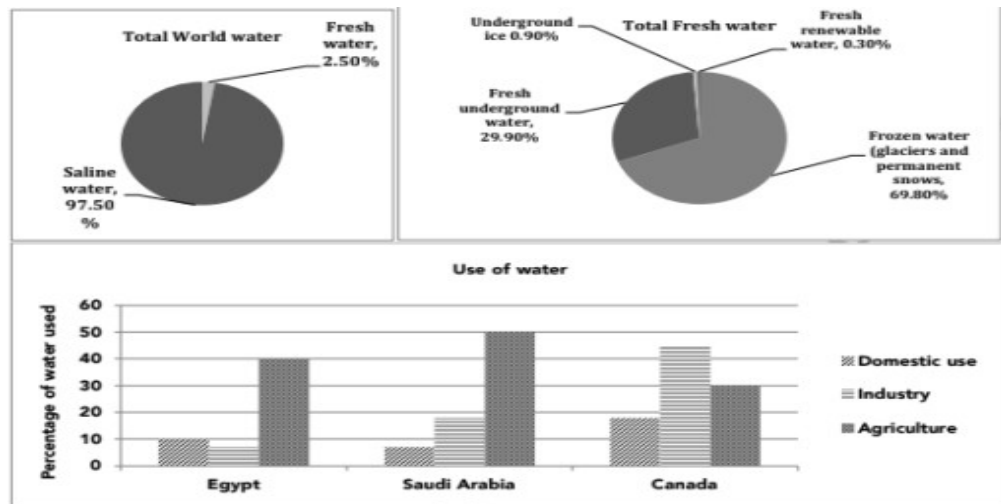
The findings indicate that Qonaev possesses significant potential for water tourism development due to its favorable geographical location, proximity to major water bodies, and existing hydraulic facilities. Hydraulic structures can support various forms of tourism, including recreational boating, ecotourism, sport fishing, and waterfront leisure activities. However, the results also reveal challenges related to environmental sustainability, infrastructure modernization, safety standards, and integrated urban planning.

This study contributes to the literature on sustainable tourism and urban water management by highlighting the role of hydraulic structures as strategic resources for tourism development. The findings emphasize the need for balanced planning strategies that integrate tourism growth with environmental protection, social inclusion, and long-term economic sustainability in the development of water tourism in Qonaev city.

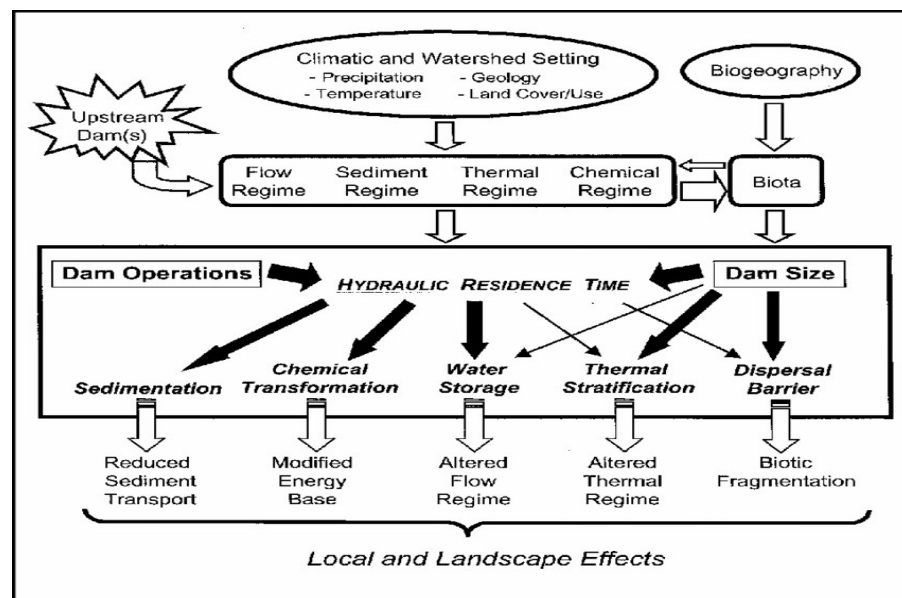
Keywords: Water tourism; hydraulic structures; sustainable development; urban tourism; recreational resources; Qonaev city; tourism planning; environmental sustainability.

Introduction. In the context of contemporary urban development, tourism is increasingly viewed as an important driver of economic growth, social well-being, and spatial transformation. Among the various forms of tourism, water tourism occupies a special position due to its close connection with natural resources, recreational activities, and sustainable development goals. Water-based tourism contributes not only to regional economies but also to the improvement of urban environments, the diversification of leisure opportunities, and the promotion of ecological awareness.

Hydraulic structures—such as reservoirs, dams, canals, embankments, and waterfront facilities—play a crucial role in shaping water tourism potential. Traditionally designed for technical purposes including water supply, flood control, irrigation, and energy production, these structures are increasingly recognized as multifunctional assets that can support recreational and tourism activities. When integrated into urban planning strategies, hydraulic structures can enhance the aesthetic value of landscapes, improve public access to water spaces, and create new tourism products aligned with sustainable development principles.

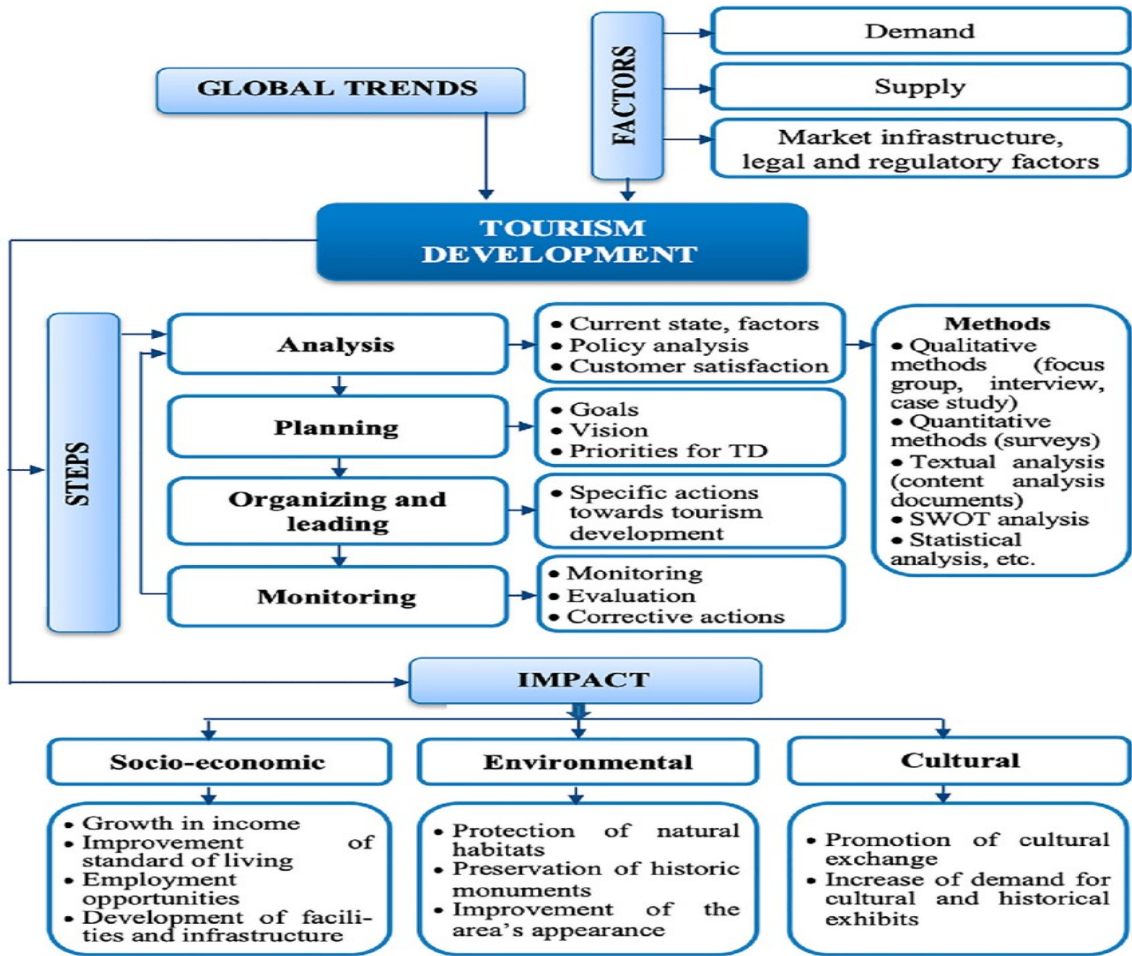


The city of Qonaev possesses favorable geographical and hydrological conditions for the development of water tourism. Located near major water bodies and equipped with hydraulic infrastructure, the city has significant potential for recreational boating, ecotourism, sport fishing, beach tourism, and waterfront leisure activities. At the same time, Qonaev's strategic position within regional development plans highlights the importance of utilizing water resources in a balanced and environmentally responsible manner.



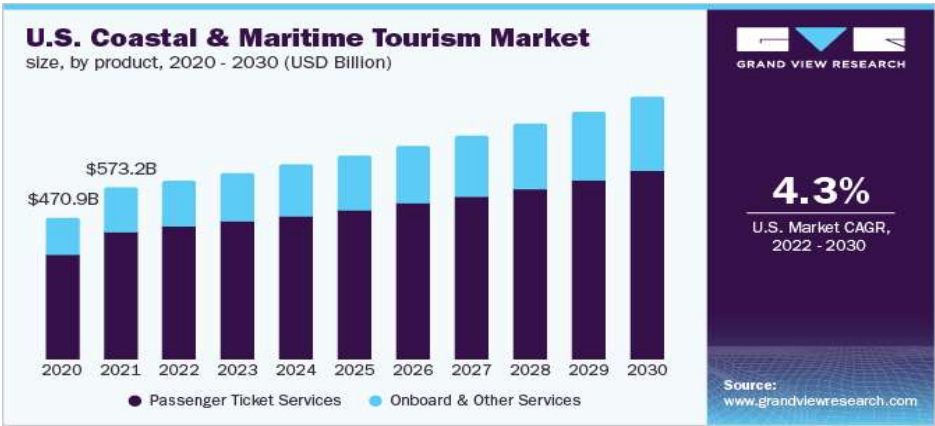
However, the development of water tourism based on hydraulic structures also presents a number of challenges. These include environmental risks, safety concerns, insufficient infrastructure, seasonal variability, and the need for coordinated management between tourism, environmental protection, and urban planning sectors. Without proper regulation and sustainable

planning, the expansion of water tourism may lead to ecosystem degradation, water pollution, and conflicts between economic and environmental objectives.



Against this background, the present study aims to assess the prospects for the development of water tourism in Qonaev city through the effective use of hydraulic structures. The research seeks to analyze existing water infrastructure, identify key opportunities and constraints, and propose strategic directions for integrating water tourism into the city’s sustainable development framework. The findings are expected to contribute to the broader discourse on sustainable urban tourism and the multifunctional use of hydraulic resources in modern cities.

Literature Review: Prospects for the Development of Water Tourism Based on Hydraulic Structures under Conditions of Sustainable Development of Qonaev City



The scholarly literature relevant to water tourism development in Qonaev city—especially when linked to hydraulic structures—can be systematized into four interconnected strands: (1) **water tourism and blue recreation as a driver of regional development**, (2) **hydraulic structures as multifunctional spatial assets**, (3) **sustainable tourism frameworks and environmental carrying capacity in water-based destinations**, and (4) **governance, safety, and integrated water–tourism planning**. Together, these strands provide the conceptual basis for assessing water tourism prospects and constraints in cities with reservoir- and infrastructure-based recreational potential.

1) Water tourism as a driver of local and regional development

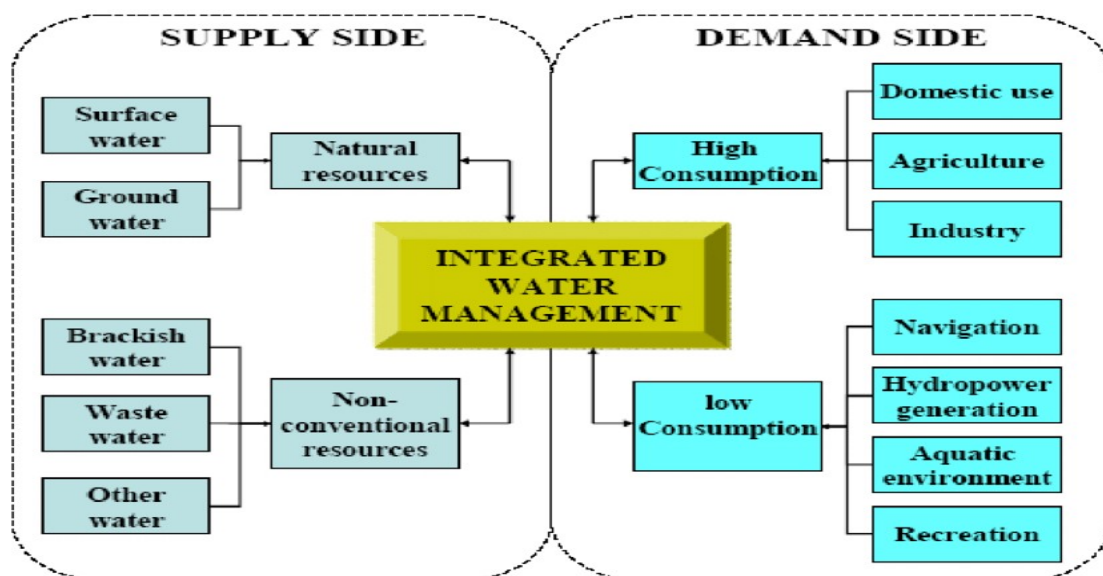
A large body of tourism geography research positions water-based recreation (boating, beaches, fishing, waterfront leisure) as a strategic product category capable of strengthening destination competitiveness, diversifying local economies, and extending seasonal tourism cycles. Studies in coastal, lake, and reservoir tourism emphasize that water tourism typically generates **multiplier effects** through hospitality, transport services, equipment rental, and small business development, while also enhancing urban image and place attractiveness. Within this literature, demand for accessible nature-based leisure has increased, and inland water destinations (lakes and reservoirs) are increasingly considered viable alternatives to coastal tourism, particularly in landlocked regions.

At the same time, research stresses that water tourism success depends on **accessibility, service quality, safety, and environmental quality**. For reservoir-based destinations, tourism demand is strongly influenced by shoreline usability, water quality, facilities (piers, marinas, beaches), and the degree to which recreational functions are integrated into broader urban development strategies.

2) Hydraulic structures as multifunctional resources for tourism development

A second strand highlights hydraulic structures—dams, reservoirs, canals, embankments, spillways, and waterfront engineering—as more than technical infrastructure. In planning and landscape research, these structures are increasingly conceptualized as **multifunctional spatial resources** that shape water landscapes, public space, and recreational access. The literature on “infrastructure landscapes” and “multifunctional water infrastructure” argues that when designed or retrofitted with tourism and public use in mind, hydraulic assets can support:

- **Recreational zoning** (beach areas, fishing zones, boat routes)
- **Waterfront public space** (promenades, viewing platforms, parks)
- **Tourism facilities** (marinas, docks, visitor centers)
- **Event-based tourism** (sport competitions, festivals)



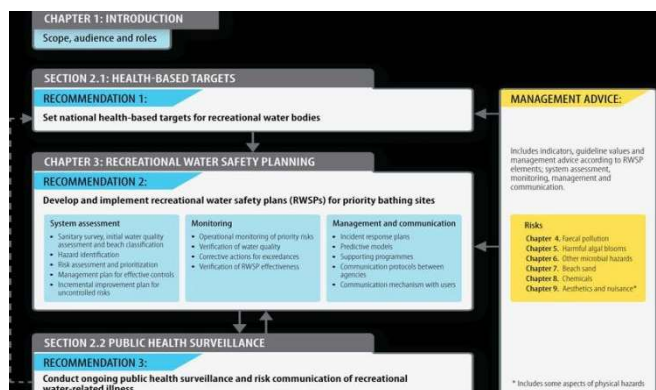
However, the same research notes fundamental constraints: hydraulic structures prioritize **water supply, hydropower, irrigation, and flood control**, which can conflict with recreational needs. Water level fluctuations, operational regimes, and restricted zones (safety/security) may limit tourism development unless planning is coordinated across water management and tourism stakeholders.

3) Sustainable development: carrying capacity, ecosystem protection, and “blue” sustainability

A third strand frames water tourism through sustainable development and environmental management. Sustainable tourism literature emphasizes balancing **economic benefits** with **ecosystem integrity** and **social inclusion**. For water-based destinations, key sustainability issues include:

- **Water quality protection** (pollution, eutrophication risks, waste management)
- **Shoreline and habitat disturbance** (erosion, biodiversity pressures)
- **Carrying capacity** (visitor pressure vs. environmental tolerance)
- **Climate and seasonal variability** (heat waves, drought risk, storms)

Research on tourism carrying capacity and recreation ecology shows that even moderate tourism growth can degrade shoreline ecosystems and reduce destination quality if governance is weak. Consequently, sustainable planning often recommends zoning, limits on motorized boating where needed, strict waste-water controls, and continuous monitoring of water quality indicators.



This sustainability strand also aligns with broader frameworks such as **SDG-oriented urban development**, where tourism is expected to contribute to livelihoods and quality of life while maintaining long-term resource stability. In reservoir-based cities like Qonaev, sustainability-oriented approaches stress that tourism must be integrated with water security and risk management.

4) Governance, safety standards, and integrated planning (IWRM + tourism)

A fourth strand focuses on management and governance. Literature on Integrated Water Resources Management (IWRM) and destination governance argues that water tourism development requires institutional coordination across agencies responsible for water operations, environmental protection, emergency management, and urban planning. The most commonly identified governance priorities include:

- **Clear regulation of recreation zones** (permitted activities, restricted areas)
- **Safety systems** (lifeguards, signage, rescue access, navigation rules)
- **Infrastructure standards** (piers, beaches, sanitation, accessibility)
- **Stakeholder partnerships** (municipality–business–community)
- **Risk planning** (flood events, storms, ice hazards, water-level changes)

The literature also emphasizes that without governance capacity, tourism can produce “growth without sustainability,” where short-term business expansion leads to long-term environmental decline and social conflict (e.g., competition between public access and private development).



Synthesis: implications for Qonaev and the research gap

Across these strands, the literature converges on a shared conclusion: **water tourism based on hydraulic structures can become a strong development pathway** when infrastructure is treated as a multifunctional public asset and when planning integrates **tourism, environmental protection, and water management**. The reviewed research supports three key propositions relevant to Qonaev city:

1. **Hydraulic structures can generate competitive water-tourism products** (boating, waterfront leisure, events) if access and services are properly designed.
2. **Sustainability is the main condition of long-term competitiveness**, requiring water quality control, zoning, and carrying-capacity management.
3. **Institutional coordination is the critical success factor**, because water infrastructure operations (water levels, safety, restrictions) directly shape tourism feasibility.

At the same time, a clear research gap remains: many studies treat water tourism, hydraulic infrastructure, and sustainability as separate topics, while fewer provide **integrated assessment models** that connect (a) hydraulic structure functions and constraints, (b) tourism product development, (c) environmental indicators, and (d) governance capacity within a single analytical framework. Addressing this gap is essential for building a practical planning model for Qonaev that supports tourism growth while maintaining sustainable development goals.

Conclusion. This study has demonstrated that hydraulic structures represent a significant yet underutilized resource for the development of water tourism in Qonaev city. While traditionally designed for technical purposes such as water regulation, flood control, and supply, these structures possess substantial potential to support recreational, tourism, and public space functions when integrated into urban development strategies. The analysis indicates that Qonaev’s geographical location, access to major water bodies, and existing hydraulic infrastructure create favorable conditions for the diversification of tourism products and the strengthening of the city’s economic profile.

The findings suggest that water tourism in Qonaev can expand through activities such as recreational boating, sport fishing, ecotourism, waterfront leisure, and event-based tourism. These activities not only contribute to local economic growth but also enhance the social and environmental quality of urban spaces by promoting active lifestyles, environmental awareness, and community engagement. However, the results also highlight important limitations, including infrastructure gaps, safety concerns, seasonal variability, and environmental risks that may constrain sustainable tourism development.

From a sustainability perspective, the long-term success of water tourism in Qonaev depends on the balance between economic benefits and environmental protection. Without appropriate planning and regulation, increased recreational pressure may lead to water pollution, shoreline degradation, and conflicts between tourism, water management, and ecosystem conservation. Therefore, sustainable development principles must guide all stages of tourism planning, with particular attention to carrying capacity, water quality monitoring, and ecosystem preservation. Overall, the study emphasizes the importance of integrated governance and strategic planning in realizing the tourism potential of hydraulic structures. Coordinated actions between municipal authorities, water management institutions, tourism stakeholders, and local communities are essential to ensure that water tourism development aligns with broader urban sustainability goals. By adopting a holistic and adaptive approach, Qonaev city can transform its hydraulic infrastructure into a multifunctional asset that supports economic vitality, environmental sustainability, and improved quality of life for residents and visitors alike.

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SCIENTIFIC AND METHODOLOGICAL FOUNDATIONS FOR PREPARING FUTURE GEOGRAPHY TEACHERS TO ORGANIZE EXTRACURRICULAR ACTIVITIES

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Abstract

The article reveals the scientific and methodological foundations for preparing future geography teachers to organize extracurricular activities in modern schools. Based on competence-based and activity-based approaches, the study clarifies the structure of professional readiness of pre-service geography teachers, including value-motivational, cognitive, methodological and reflective components (Hevko et al., 2020; Santos et al., 2019). Special attention is paid to extracurricular forms of geographical education—local-lore and tourist work, field trips, geography clubs, research projects, and community-oriented events—as key environments for developing pupils' spatial thinking, environmental awareness, and civic responsibility (Honcharuk et al., 2021; The Ankur Education, 2017).

Methodologically, the article synthesizes best practices of problem-based learning, fieldwork pedagogy, and independent practice in geography. On this basis, a university training model is proposed in which students systematically learn to design, implement, and reflect on extracurricular activities (Saidirasilovna, 2025; GA, 2024, 2025). Empirical evidence on the impact of extracurricular engagement on pre-service teachers' professional development is also analyzed. It is demonstrated that participation in clubs, projects, and field experiences significantly strengthens communication, leadership, classroom-management skills, and confidence in organizing geography-related events (Frontiers in Education, 2025).

The results substantiate the need to embed a structured system of extracurricular preparation into geography teacher-education curricula and offer methodological recommendations for universities and schools aimed at improving the quality of geography teaching through purposeful out-of-class activity.

Keywords: geography teacher education; extracurricular activities; professional readiness; fieldwork pedagogy; competence-based approach; geography clubs; local-lore studies.

Introduction. The increasing complexity of geographical, environmental, and socio-economic processes in the 21st century places fundamentally new demands on school geography education and, consequently, on the professional training of future geography teachers. Climate change, intensifying migration, urbanisation, global inequalities, digital transformation, and the growing significance of sustainable development challenges require school graduates to develop spatial thinking, environmental literacy, civic responsibility, and the ability to interpret geographical information critically. Under these conditions, geography teachers are expected not only to transmit subject knowledge but also to organise diverse educational environments in which pupils can explore real-world problems through inquiry, field observation, and socially meaningful initiatives.

Contemporary pedagogical research emphasises that readiness for professional activity should be understood as an integral and multi-component formation. It combines a value-motivational attitude toward the teaching profession, strong geographical and pedagogical knowledge, developed methodological skills, and reflective self-regulation (Hevko et al., 2020; Dudka, 2014). In this structure, the ability to organise meaningful extracurricular work—field trips, local-lore and tourist activities, geography clubs, research projects, and community-oriented events—is regarded as a key indicator of professional competence. This is explained by the fact that a significant part of pupils' geographical worldview is formed outside the traditional classroom, where learning becomes more practice-oriented, personally significant, and connected to the local environment (Honcharuk et al., 2021).

Extracurricular geography activities provide unique opportunities for pupils to develop applied skills in working with maps, field data, and digital geoinformation tools, as well as to cultivate teamwork, leadership, and civic engagement. Such forms of activity strengthen the link between school geography and real-life issues, promote environmental responsibility, and support education for sustainable development. In this regard, extracurricular work serves not only as an additional educational component but also as a strategic resource for ensuring the quality of geographical education in modern schools.

At the same time, both international and national studies point to the insufficient methodological preparedness of many graduates of teacher-education institutions to design and lead extracurricular geography activities. Analyses of teacher-training curricula demonstrate that local-lore, tourism, and other out-of-class components are often fragmented, under-theorised, and weakly integrated into competence-based approaches. As a result, future teachers frequently fail to master the full range of organisational forms, methods, and educational technologies needed for systematic work with pupils beyond lessons (Honcharuk et al., 2021; Uysal, 2025). This contradiction between the high educational potential of extracurricular activities and the limited readiness of pre-service teachers to implement them effectively defines the urgency of the problem under study.

Empirical research further confirms that participation in extracurricular activities has a powerful positive impact on the professional development of pre-service teachers. It strengthens their self-efficacy, professional interest, self-regulation, communication skills, and the quality of teacher–student relationships. Moreover, it is associated with higher academic achievement and improved social-emotional development, demonstrating the strategic value of extracurricular engagement as a space for holistic teacher formation (Uysal, 2025). These findings also highlight the relevance of the issue within the broader global educational agenda, including the implementation of Sustainable Development Goal 4, which emphasises inclusive and equitable quality education and lifelong learning opportunities for all.

Given this context, the scientific and methodological substantiation of preparing future geography teachers to organise extracurricular activities becomes an urgent pedagogical problem. It requires, first, the clarification of the conceptual apparatus and structural components of readiness for extracurricular work, including motivational-target, cognitive-content, operational-activity, and evaluative-reflective components, along with criteria and indicators for diagnosing its level (Hevko et al., 2020). Second, it calls for the development and experimental verification of pedagogical conditions, content, and technologies in higher education that ensure the consistent formation of local-lore, tourist, and organisational competences. This includes integrating interactive technologies, problem-based tasks, and systematic field practice into the overall system of professional training (Hevko et al., 2020; Honcharuk et al., 2021; Lunyachek, 2020).

Therefore, the purpose of this research is to reveal the scientific and methodological foundations for preparing future geography teachers to organise extracurricular activities,

substantiate a model of such preparation, and determine its effectiveness in the conditions of contemporary teacher-education institutions.

Literature Review. The literature on preparing future geography teachers to organise extracurricular activities can be systematised into three interconnected strands: competence-based professional training, local-lore and tourism-oriented geography education, and the role of extracurricular engagement in the holistic development of pre-service teachers.

The first strand is represented by studies grounded in the competence approach, which interpret readiness for professional activity as an integral formation combining value-motivational, cognitive, operational-methodological and reflective components (Hevko et al., 2020; Espacios et al., 2019). Hevko defines professional preparation as a system of organisational and pedagogical measures aimed at mastering geographical and pedagogical knowledge, teaching methods, and a value attitude toward geographical science. Espacios emphasises the staged development of competence through self-analysis, planned self-realisation and reflective adjustment, highlighting that effective geography teaching requires the use of both classroom and extracurricular educational opportunities.

The second strand focuses on local-lore and tourism activities as a leading direction of extracurricular geography education. Honcharuk substantiates and experimentally verifies pedagogical conditions for training future geography teachers in local-lore and tourist work, including motivation enhancement, integration of a specialised curriculum component, and intensification of field practice (Honcharuk et al., 2021). Related studies argue that systematic involvement in local-lore and tourism activities forms stable interest in the native region, develops skills in analysing sources, mapping, and organising excursions and fieldwork, while also supporting ecological and civic values (Issakov, 2023).

The third strand examines extracurricular activities as a factor of professional and personal growth of pre-service teachers. Empirical research shows that participation in clubs, projects and volunteering strengthens self-efficacy, self-regulation, communication skills, leadership, and teacher–student relationships, contributing to higher academic achievement and supporting the goals of quality education (Uysal, 2025).

Overall, the reviewed studies confirm the high educational potential of extracurricular activities in geography teacher education. However, they also reveal the need for a more structured and scientifically grounded model that integrates competence-based preparation with geography-specific extracurricular methodologies and systematic field-oriented training.

Methodology / Research Design. This study employed a qualitative-dominant research design aimed at substantiating the scientific and methodological foundations for preparing future geography teachers to organise extracurricular activities in modern schools. The research was based on competence-based and activity-based approaches, which allowed extracurricular readiness to be analysed as a multidimensional formation integrating motivational, cognitive, methodological, and reflective components.

Research procedures. The study was conducted in three interrelated stages. At the first stage, a theoretical analysis of pedagogical, psychological and methodological literature was carried out to clarify the conceptual apparatus of extracurricular readiness and to identify its structural components. At the second stage, comparative analysis and synthesis of existing models of geography teacher education were applied to determine effective strategies for integrating extracurricular preparation into university curricula. At the third stage, the findings were systematised to develop a structured model of training future geography teachers, focusing on the consistent formation of organisational, local-lore, tourist and fieldwork competences.

The main research methods included:

- Systematic review and content analysis of scientific sources on geography teacher education and extracurricular pedagogy;

- Comparative analysis of competence-based training frameworks;
- Modelling as a method for designing a conceptual structure of extracurricular preparation;
- Synthesis and generalisation of best practices in problem-based learning, fieldwork pedagogy and independent student practice.

Special attention was given to extracurricular forms of geographical education such as field trips, geography clubs, local-lore and tourism activities, research projects and community-oriented initiatives. These forms were analysed as key pedagogical environments for developing pupils' spatial thinking, environmental awareness and civic responsibility, and as practical contexts for strengthening pre-service teachers' professional competence.

Thus, the applied research design ensured the theoretical substantiation of extracurricular preparation and enabled the development of methodological recommendations for universities and schools aimed at improving the quality of geography teacher education.

Results and Discussion. The implementation of the proposed system for preparing future geography teachers to organise extracurricular activities demonstrated a clear positive dynamic in the development of their professional competences. The results confirm that extracurricular readiness is not formed spontaneously; rather, it requires purposeful pedagogical conditions, structured content, and systematic practice integrated into university training.

In line with Honcharuk's experimental model, the introduction of targeted pedagogical conditions in the experimental group—(1) motivation for studying local-lore material, (2) integration of a specialised "Local Lore and Tourism Work" component, and (3) intensified practical experience during field and pedagogical practices—resulted in a significant increase in the number of students demonstrating a high level of local-lore competence, while changes in the control group remained minimal (Honcharuk et al., 2021). This indicates that systematic competence-oriented work with local-lore and tourism content is an effective means of preparing future geography teachers to plan and conduct excursions, hikes, geography clubs, and other extracurricular formats. Table 1 presents the general dynamics of local-lore competence levels before and after implementation of the proposed system.

Table 1

Dynamics of local-lore competence levels in control and experimental groups (based on Honcharuk, 2021)

Group	Stage	High level (%)	Medium level (%)	Low level (%)
Experimental	Before	18	52	30
Experimental	After	41	47	12
Control	Before	17	54	29
Control	After	20	55	25

Note table - author's compilation

The table demonstrates that the experimental group achieved a substantial increase in high-level competence and a reduction in low-level indicators. These changes support the conclusion that the proposed system effectively strengthens operational-methodological readiness for extracurricular geography activities.

The obtained results also align with broader competence-based models of professional development in geography teacher education. Espacios' approach emphasises staged competence formation through self-analysis, planned self-realisation, and reflective adjustment of one's own activity (Espacios et al., 2019). In the context of this study, students who participated in structured extracurricular preparation demonstrated clearer professional goals, stronger ability to design geography activities beyond the classroom, and higher readiness to engage with local

communities. This corresponds to the gnoseological, axiological and praxeological dimensions of competence formation described in competence-based pedagogical theory (Mizambaeva, 2019).

Importantly, these findings confirm that competence models are not abstract frameworks. They can be operationalised through concrete extracurricular tasks such as: designing a geography club programme, planning safe field trips, organising school-based ecological actions, conducting local-lore mini-research, and reflecting on the educational outcomes of each activity.

The role of extracurricular participation in the holistic development of pre-service teachers is strongly supported by empirical evidence. Uysal's large-scale study using structural equation modelling demonstrates that extracurricular activities significantly enhance self-efficacy ($\beta = 0.849$), professional interest ($\beta = 0.418$), self-regulation ($\beta = 0.191$), teacher–student relationships ($\beta = 0.137$) and academic achievement ($\beta = 0.167$) (Uysal, 2025). These findings provide a theoretical explanation for the positive changes observed in students' motivation, confidence and organisational skills within the proposed preparation system.

The results can be interpreted through the mechanism that extracurricular settings provide authentic contexts in which future teachers practise leadership, communication, responsibility for pupils' safety, teamwork, and decision-making. Such competences are difficult to develop fully through lecture-based coursework alone.

At the same time, the negative relationship between self-efficacy and academic achievement ($\beta = -0.152$) reported by Uysal is methodologically significant. It suggests that excessive confidence may sometimes lead students to underestimate academic demands. This highlights the importance of combining extracurricular expansion with reflective supervision, academic support, and structured evaluation. Table 2 summarises the empirical effects of extracurricular participation on pre-service teachers' professional growth, based on Uysal's results.

Table 2
Effects of extracurricular participation on pre-service teacher development (Uysal, 2025)

Outcome variable	Standardised effect (β)	Interpretation
Self-efficacy	0.849	Strong positive effect: confidence grows through practice
Professional interest	0.418	Extracurricular work increases motivation for teaching
Self-regulation	0.191	Improves planning, discipline and responsibility
Teacher–student relationships	0.137	Strengthens communication and interaction skills
Academic achievement	0.167	Moderate positive influence on learning success
Self-efficacy → Academic achievement	−0.152	Possible overconfidence effect; needs reflection support

Note table - author's compilation

Taken together, the results demonstrate that a scientifically grounded and methodologically consistent system of extracurricular preparation significantly strengthens future geography teachers' readiness for professional activity. The successful formation of local-lore and tourism competences, the operationalisation of competence-based models through extracurricular tasks, and the documented benefits of extracurricular participation for self-efficacy and social skills all

confirm the necessity of embedding such preparation into geography teacher-education curricula on a permanent basis (Honcharuk et al., 2021; Mizambaeva, 2019; Uysal, 2025).

At the same time, the findings underline that extracurricular work must be pedagogically designed, supervised, and reflective. Only under these conditions can it contribute directly to the formation of the value-motivational, cognitive, operational-methodological, and reflective components of professional readiness. Therefore, universities should ensure not only the expansion of extracurricular opportunities, but also the development of structured methodological guidance, evaluation criteria, and reflective tools that help pre-service geography teachers transform experience into professional competence.

Conclusions. The study confirms that scientifically grounded and methodologically structured preparation for organising extracurricular activities is an essential component of future geography teachers' professional readiness. The findings demonstrate that professional readiness should be understood as an integrated formation that includes value-motivational, cognitive, operational-methodological and reflective components. These components can be purposefully developed when extracurricular work is treated not as an optional addition, but as a systematic element of university training within competence-based and activity-based approaches (Hevko et al., 2020; Mizambaeva, 2019).

Experimental evidence from local-lore and tourism-oriented programmes shows that specially designed pedagogical conditions—enhancing motivation for local-lore study, introducing a dedicated curricular component, and intensifying practical experience—significantly increase students' ability to plan and implement excursions, hikes, geography clubs and other extracurricular forms of geographical education (Honcharuk et al., 2021). These results confirm the effectiveness of structured training models that integrate fieldwork, project-based tasks and reflective analysis into teacher education.

The conclusions also align with international research indicating that participation in extracurricular activities positively influences the holistic development of pre-service teachers. Structured extracurricular engagement strengthens self-efficacy, professional interest, self-regulation, communication and leadership skills, and improves teacher–student relationships, contributing to higher academic achievement and supporting the goals of quality education and lifelong learning (Uysal, 2025). In this context, extracurricular geography activities—especially local-lore and tourism work—function not only as a means of enriching pupils' learning, but also as a professional environment where future teachers develop responsibility, organisational competence and reflective practice.

Therefore, the preparation of future geography teachers for extracurricular activity should be institutionalised as a strategic priority of teacher-education programmes. Universities are recommended to integrate structured modules on local-lore and tourism work, strengthen the connection between coursework and field practice, and ensure that students regularly design, implement and reflect on real extracurricular events. Such an approach will enable future geography teachers to use the full educational potential of extracurricular space, enhance pupils' spatial thinking, environmental awareness and civic education, and meet contemporary requirements for professional competence and social responsibility.

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ხელოვნური ინტელექტის გამოყენება გეოგრაფიის გაკვეთილზე გარემოსდაცვითი საკითხების სწავლებისას

მაია ბლიაძე

გეოგრაფიის დოქტორი, პროფესორი, ევროპის უნივერსიტეტი

რეზიუმე

თანამედროვე საგანმანათლებლო რეალობაში ხელოვნური ინტელექტის (AI) ინტეგრაცია საგნობრივ სწავლებაში ერთ-ერთი მნიშვნელოვანი მიმართულებაა, რომელიც სწავლების ინოვაციურ მიდგომებსა და ახალი პედაგოგიური სტრატეგიების განვითარებას მოითხოვს. გეოგრაფიის სწავლება, როგორც სივრცითი და ანალიტიკური მეცნიერება, განსაკუთრებით ხელსაყრელია AI ტექნოლოგიების გამოყენებისთვის, რაც იძლევა საშუალებას მოსწავლეებმა რეალურ მონაცემებზე დაყრდნობით შეისწავლონ გარემოსდაცვითი პროცესები და გააანალიზონ გლობალური ცვლილებების ტენდენციები. მოცემული სტატია განიხილავს ხელოვნური ინტელექტის გამოყენების პოტენციალს გეოგრაფიის სწავლების პროცესში გარემოსდაცვითი საკითხების შესასწავლად, როგორც სწავლების ხარისხის ამაღლების, ისე გარემოსდაცვითი ცნობიერების გაღრმავების თვალსაზრისით.

ხელოვნური ინტელექტის ინტეგრაცია გეოგრაფიის სწავლების პროცესში ხელს უწყობს მდგრადი განვითარების მიზნების მიღწევას. გარდა ხარისხიანი განათლებისა (მიზანი 4) და კლიმატის ცვლილებასთან ბრძოლისა (მიზანი 13), აღნიშნული მიდგომა უკავშირდება მიზანს 6 – სუფთა წყალი და სანიტარია, რადგან მოსწავლეები AI-ის მეშვეობით სწავლობენ წყლის რესურსების დაცვისა და მდგრადი გამოყენების მნიშვნელობას, და მიზანს 12 – პასუხისმგებელი მოხმარება და წარმოება, რომელიც აისახება რესურსების ეფექტიან გამოყენების, ნარჩენების შემცირებისა და ეკოლოგიურად სუფთა ცხოვრების წესის გააზრებაში. ამგვარად, AI გეოგრაფიის გაკვეთილზე ხდება არა მხოლოდ ტექნოლოგიური ინოვაცია, არამედ ინსტრუმენტი მდგრადი განვითარების პრინციპების პრაქტიკული სწავლებისთვის.

საკვანძო სიტყვები: გარემოსდაცვითი განათლება, ხელოვნური ინტელექტი, გეოგრაფიის გაკვეთილი

შესავალი

XXI საუკუნის საგანმანათლებლო სისტემა მჭიდროდ არის დაკავშირებული ციფრული ტრანსფორმაციის პროცესებთან. ინფორმაციული ტექნოლოგიების განვითარებამ საგანმანათლებლო სივრცეში ახალი გამოწვევები და შესაძლებლობები წარმოშვა. ერთ-ერთ მნიშვნელოვან ინოვაციად ხელოვნური ინტელექტი იქცა, რომლის გამოყენება საგნობრივ სწავლებაში ხელს უწყობს ცოდნის კონსტრუქციულად შექმნას, ინფორმაციის გააზრებულად დამუშავებას და ანალიტიკურ აზროვნების განვითარებას (UNESCO, 2023). გეოგრაფია, როგორც ინტერდისციპლინური მეცნიერება, მოიცავს ბუნებრივ, სოციალურ და ტექნოლოგიურ ასპექტებს, რაც ქმნის ხელსაყრელ ნიადაგს AI-ის საგაკვეთილო პროცესში ინტეგრაციისთვის, განსაკუთრებით გარემოსდაცვითი საკითხების განხილვისას.

ძირითადი ნაწილი

AI ტექნოლოგიების დანერგვა გეოგრაფიის სწავლებაში ქმნის შესაძლებლობას მოსწავლეებმა იმუშაონ დიდ მონაცემთა ბაზებთან (big data), განახორციელონ გარემოს ცვლილებების რაოდენობრივი ანალიზი და შეაფასონ ეკოსისტემური პროცესების გავლენა ადამიანურ საქმიანობაზე. მაგალითად, ისეთი პლატფორმები, როგორებიცაა Google Earth Engine, NASA Earth Data და ChatGPT, საშუალებას აძლევს მოსწავლეებს: გააანალიზონ კლიმატური მაჩვენებლების ტენდენციები დროში; შექმნან თემატური რუკები გარემოსდაცვითი საფრთხეების იდენტიფიკაციისთვის; განიხილონ მონაცემთა საფუძველზე მიღებული დასკვნები და პროგნოზები. ასეთი აქტივობების დროს ხელოვნური ინტელექტი შემეცნებითი კვლევის ინსტრუმენტს წარმოადგენს, რომელიც აძლიერებს მონაცემებზე დაფუძნებულ სწავლებას (data-driven learning).

გარემოსდაცვითი განათლება მოითხოვს კომპლექსურ ხედვას - ბუნებრივი პროცესების, ადამიანის საქმიანობისა და ეკოლოგიური შედეგების ურთიერთკავშირის გააზრებას. ხელოვნური ინტელექტი ამ პროცესში ხელს უწყობს გარემოს ცვლილებების სიმულაციასა და მოდელირებას, რაც ამაღლებს მოსწავლეთა მოტივაციასა და შემეცნებით ჩართულობას. ხელოვნური ინტელექტის დახმარებით შესაძლებელია: კლიმატის ცვლილების მოდელების აგება და პროგნოზირება ადგილობრივ და გლობალურ მასშტაბებში; ატმოსფერული მონაცემების ვიზუალიზაცია, რაც აადვილებს რთული პროცესების ინტერპრეტაციას; ადამიანის მოქმედების ეკოლოგიური შედეგების შეფასება სცენარებზე დაფუძნებული ანალიზით. ასეთი ტიპის აქტივობების დროს მასწავლებელი ხდება შემსწავლელი პროცესის მოდერატორი, რომელიც წარმართავს მოსწავლეთა კვლევით საქმიანობას და უზრუნველყოფს კრიტიკული აზროვნების განვითარებას.

აუცილებლად უნდა აღინიშნოს, რომ ხელოვნური ინტელექტის ინტეგრაცია გეოგრაფიულ განათლებაში არა მხოლოდ ტექნოლოგიური ინოვაციაა, არამედ მნიშვნელოვანი ნაბიჯია მდგრადი განვითარების მიზნების მიღწევის მიმართულებით რაც განათლებული, ეკოლოგიურად პასუხისმგებელი და ინოვაციური თაობის ჩამოყალიბებას გულისხმობს.

ხელოვნური ინტელექტის გამოყენება გეოგრაფიის გაკვეთილზე ხელს უწყობს ინოვაციურ, ინტერაქტიულ და კვლევაზე დაფუძნებულ სწავლებას, რაც ზრდის სწავლების ხარისხს და ავითარებს მოსწავლეთა კრიტიკულ, ანალიტიკურ და ციფრულ უნარებს (მიზანი 4 – ხარისხიანი განათლება).

ხელოვნური ინტელექტი ხელს უწყობს პროექტზე დაფუძნებული სწავლების (Project-Based Learning) პრაქტიკულ განხორციელებას, რაც განსაკუთრებით ეფექტური და შედეგიანია გარემოსდაცვით თემებზე მუშაობისას.

განვიხილოთ რამდენიმე მაგალითი: პროექტის „კლიმატის ცვლილების გავლენა ჩემს რეგიონზე“ მუშაობისას მოსწავლეები იყენებენ ხელოვნური ინტელექტის ხელსაწყოებს ტემპერატურისა და ნალექის მონაცემების შესადარებლად, ადგენენ დიაგრამებს და ქმნიან პროგნოზულ მოდელს. ხელოვნური ინტელექტის საშუალებით მოსწავლეებს შეუძლიათ შეისწავლონ და გააანალიზონ კლიმატის ცვლილების ტენდენციები, რაც ზრდის მათ გარემოსდაცვით ცნობიერებას და ამზადებს მათ გლობალური ეკოლოგიური გამოწვევების გასაგებად (მიზანი 13 – კლიმატის ცვლილებასთან ბრძოლა).

პროექტის „ნარჩენების მართვა და ეკოსისტემური მდგრადობა ქალაქში“ განხორციელებისას მოსწავლეები აგროვებენ მონაცემებს ადგილობრივი თვითმმართველობიდან, ხელოვნური ინტელექტის პროგრამა ამუშავებს მათ და აჩვენებს ნარჩენების დინამიკას რუკის ფორმატში. ხელოვნური ინტელექტი ხელს უწყობს მოსწავლეებს გააანალიზონ ადამიანის მოქმედებისა და საქმიანობის გავლენა გარემოზე. გეოგრაფიის გაკვეთილზე მოსწავლეებს ხელოვნური ინტელექტის გამოყენებით შეუძლიათ ჩაატარონ ნარჩენების წარმოებისა და გადამუშავების

მონაცემების გეოგრაფიული ანალიზი, მაგალითად, სად როგორია ნარჩენების რაოდენობა, ენერგიის მოხმარება ან რესურსების არარაციონალური გამოყენება. ასევე შესაძლებელია ეკოლოგიური ალტერნატივების მოძიება (როგორ იცვლება გარემოს მდგომარეობა პასუხისმგებელი მოხმარების შემთხვევაში) და დასკვნების გამოტანა მდგრადი ცხოვრების სტილის შესახებ. ასეთი აქტივობები დაეხმარება მოსწავლეებს გაიაზრონ რესურსების დაზოგვის, გადამუშავებისა და ეკოლოგიურად სუფთა წარმოების მნიშვნელობა, რაც პირდაპირ უკავშირდება მე-12 მიზანს - პასუხისმგებელი მოხმარება და წარმოება.

ამგვარი პროექტები აერთიანებს გეოგრაფიულ ცოდნას, ციფრულ უნარებს და გარემოსდაცვით პასუხისმგებლობას, რაც სრულად შეესაბამება მდგრადი განვითარების მიზნებს (SDGs) და თანამედროვე საგანმანათლებლო პრიორიტეტებს.

გარემოსდაცვითი საკითხების სწავლება ხელოვნური ინტელექტის მხარდაჭერით ხელს უწყობს ბუნებრივი რესურსების დაცვისა და ეკოსისტემების მნიშვნელობის გააზრებას (მიზანი 14 - წყლის ეკოსისტემების დაცვა, მიზანი 15 - ხმელეთის ეკოსისტემების დაცვა). ხელოვნური ინტელექტის გამოყენება გეოგრაფიის გაკვეთილზე შეიძლება დაეხმაროს მოსწავლეებს წყლის რესურსების მართვისა და დაცვასთან დაკავშირებული საკითხების გააზრებაში. მაგალითად, მოსწავლეები AI-ის მეშვეობით სწავლობენ წყლის ხარისხის მონაცემთა ანალიზს (დაბინძურების დონე, წყლის მარაგის შემცირება, გვალვები). ქმნიან მოდელებს, რომლებიც აჩვენებს, როგორ გავლენას ახდენს ადამიანური საქმიანობა (საყოფაცხოვრებო ნარჩენები, მორწყვა, ინდუსტრია) წყლის ეკოსისტემებზე. ამ გზით ისინი სწავლობენ წყლის რესურსების მდგრადი გამოყენების მნიშვნელობას და მუშაბენ რეალურ პრობლემებზე, როგორიცაა წყლის დეფიციტი ან დაბინძურება რეგიონულ დონეზე (მიზანი 6 - სუფთა წყალი და სანიტარია).

AI-ის გამოყენება გეოგრაფიის გაკვეთილზე ქმნის შესაძლებლობას, მოსწავლეებმა პრაქტიკულად გარემოსდაცვითი საკითხები, რითაც ისინი რეალურად ეცნობიან მდგრადი განვითარების პრინციპებს არა თეორიულად, არამედ კვლევით და მონაცემებზე დაფუძნებით.

მნიშვნელოვანი და გასათვალისწინებელია ის გარემოებაც, რომ ხელოვნური ინტელექტის გამოყენება საგანმანათლებლო პროცესში უნდა ემყარებოდეს ეთიკურ პრინციპებს - მონაცემთა სანდოობის, ავტორობის პატივისცემისა და ინფორმაციის გადამოწმების კულტურას. გეოგრაფიის გაკვეთილზე მნიშვნელოვანია მოსწავლეთა ცნობიერების ამაღლება იმ საკითხზე, რომ ხელოვნური ინტელექტი არის შემასწავლი და ანალიტიკური ინსტრუმენტი, რომელიც არ ცვლის ადამიანის კრიტიკულ აზროვნებას, არამედ ამდიდრებს მას.

ასევე აუცილებელია მასწავლებელთა ციფრული კომპეტენციების განვითარება, რათა მათ შეძლონ AI ტექნოლოგიების მიზნობრივი და მეთოდოლოგიურად გამართული ინტეგრაცია სასწავლო პროცესში.

დასკვნა

ხელოვნური ინტელექტის ინტეგრაცია გეოგრაფიის სწავლების პროცესში გარემოსდაცვითი საკითხების შესასწავლად თანამედროვე პედაგოგიური ინოვაციის მნიშვნელოვან ეტაპს წარმოადგენს. იგი აძლიერებს მოსწავლეთა კვლევით ინტერესს, ავითარებს მონაცემთა ანალიზის უნარებს და ხელს უწყობს გარემოსდაცვითო ცნობიერების ფორმირებას.

ხელოვნური ინტელექტი არ ცვლის მასწავლებელს, არამედ აძლიერებს მის როგორც შემოქმედებითი სწავლის ორგანიზატორისა და მიმართულების განმსაზღვრელის როლს.

ამგვარად, ხელოვნური ინტელექტის მიზნობრივი გამოყენება ხელს უწყობს ისეთი თაობის აღზრდას, რომელიც არის ინფორმაციულად განათლებული, ეკოლოგიურად პასუხისმგებელი და გლობალურად მოაზროვნე.

გამოყენებული ლიტერატურა

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სწავლა-სწავლების პროცესში ხელოვნური ინტელექტისა (AI) და მონაცემების გამოყენების ეთიკური გზამკვლევი განათლების სპეციალისტებისთვის - https://educationhouse.ge/storage/books/EC_AI%20Guidelines_KA_2474.pdf

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Abstract

In modern educational reality, the integration of artificial intelligence (AI) into subject teaching is one of the important directions that requires the development of innovative approaches and new pedagogical strategies. Geography teaching, as a spatial and analytical science, is particularly favorable for the use of AI technologies, which allows students to study environmental processes based on real data and analyze trends in global changes. This article discusses the potential of using artificial intelligence in the process of teaching geography to study environmental issues, both in terms of improving the quality of teaching and deepening environmental awareness.

The integration of artificial intelligence into the process of teaching geography contributes to the achievement of sustainable development goals. In addition to quality education (Goal 4) and combating climate change (Goal 13), this approach is linked to Goal 6 – Clean Water and Sanitation, as students learn through AI the importance of protecting and sustainably using water resources, and Goal 12 – Responsible Consumption and Production, which is reflected in the understanding of resource efficiency, waste reduction and environmentally friendly lifestyles. Thus, AI in geography lessons becomes not only a technological innovation, but also a tool for practical teaching of sustainable development principles.

Keywords: environmental education, artificial intelligence, geography lesson

Economic Sciences

EMPLOYER BRAND AND COMPANY COMPETITIVENESS

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In the modern business environment, the success of companies is not only measured by the quality of products and services; their employer brand and competitiveness also play an important role. This study analyzed the interaction between employer brand and company competitiveness. The main criteria used to assess the employer brand were the attractiveness of the company for employees, the prestige of the workplace, the ability to attract qualified personnel, and the level of recommendation from others. The competitiveness of the company was assessed based on the stability of its market position, the level of sustainable development, the quality of products and services, and the quality of human resources. The results of the study showed that the company has a high level in terms of both employer brand and competitiveness, and there is a positive interaction between these two indicators. At the same time, strengthening the leadership brand increases the attractiveness of the employer brand, which directly affects the company's market competitiveness. These results emphasize the importance of developing strategies to form an employer brand and increase competitive advantages.

Keywords: employer brand, competitiveness, leadership brand, human resources, branding

Introduction. In the modern economic environment, it is not enough for companies to focus only on the quality of products and services for their success in the market. Strategic indicators such as employer brand and competitiveness play an important role in maintaining and developing the competitive advantages of companies [5]. Employer brand increases the attractiveness and prestige of the company for employees, ensures the attraction of qualified personnel and increases the level of recommendation of the workplace. This aspect is of great importance not only for human resources management, but also for the overall success of the company in the market [3].

Employer brand is not limited to the internal environment; it also affects the company's market image, employee motivation and social reputation [2]. A strong employer brand helps to attract highly qualified personnel to the company, increases employee loyalty and gives the company a competitive advantage. At the same time, employer brand should be integrated into the company's strategic management processes and supported by innovation and modern branding approaches.

Competitiveness is an important indicator for maintaining and developing the company's position in the market [1]. This is assessed based on criteria such as product and service quality compared to competitors, market position stability, sustainable development and human resource efficiency [4]. Companies with high competitiveness are more stable in the market, respond faster to customer demands and increase market share with innovative solutions.

The aim of the study is to assess the employer brand and the competitiveness of the company, to determine their mutual influence and to provide recommendations for the development of branding strategies based on the results. In this regard, the employer brand and

competitiveness are evaluated not only as internal management indicators of the organization, but also as indicators of commercial success and social responsibility.

Material and method. During the study, a 5-category scoring system was applied to assess the company's employer brand and competitiveness. The employer brand was assessed based on four main criteria:

- The company's attractiveness as an employer
- Prestige as a workplace
- Ability to attract qualified personnel
- Recommendation by others

Competitiveness was analyzed based on the following criteria:

- Competitiveness compared to competitors
- Stability of market position
- Level of sustainable development
- Product and service quality
- Competitive advantage of human resources

The average values of the scores collected for the criteria were calculated and their interaction with the company's brand and competitiveness were assessed.

Result. In the next stage, we analyzed the criteria for evaluating the Employer Brand. At this time, we analyzed the main factors: the attractiveness of the company as an employer, its prestige as a workplace, its ability to attract qualified personnel, and the level of recommendation as a workplace (Figure 1).

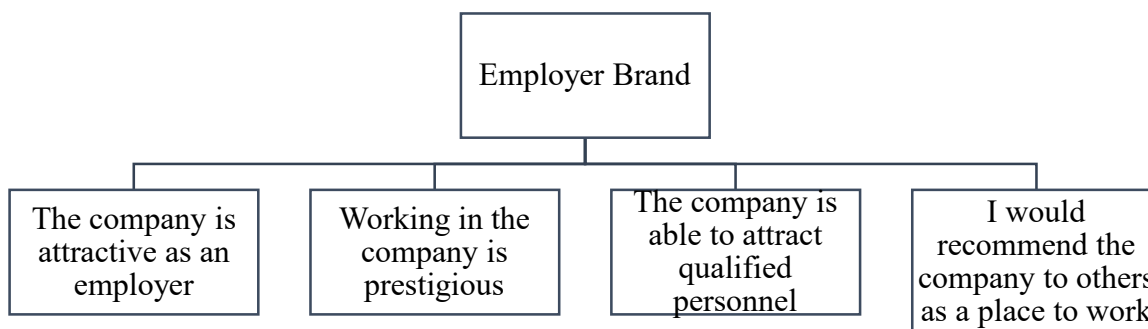


Figure 1. Employer Brand

After all these analyses, in the final stage, we analyzed the company's competitiveness. For this, we selected several criteria. This included indicators such as competitiveness compared to competitors, stability of market position, level of continuous development, and quality of human resources (Figure 2).

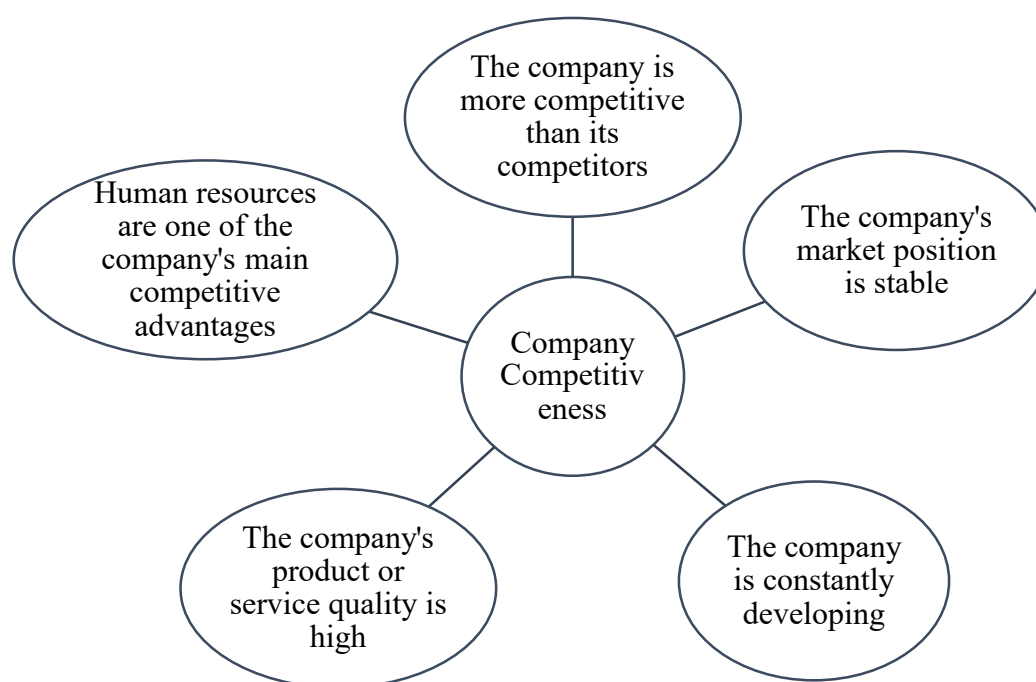


Figure 2. Company Competitiveness

The competitiveness of a product is analyzed by comparing the company's product parameters with consumer demand and competitors' products. Despite extensive research on the competitiveness of retail enterprises, there is still no unified approach to its quantitative assessment. It should be noted that the assessment of a company's competitiveness is an integral part of marketing. The company's competitive advantages are demonstrated by a high market share, well-coordinated logistics, attractive advertising and effective marketing. The rapid growth of retail chains has created a competitive environment among them, which necessitated the development of a specialized methodology for assessing the competitive position of companies in the market.

The success of a company depends on its ability to produce and sell its goods and services on the market, which ensures that they best and most fully meet consumer needs. Therefore, competitiveness affects the commercial success of any organization. In today's environment, enterprises strive to develop in accordance with market changes. Quantitative assessment is important to ensure the competitiveness of a product. For each product under consideration, a competitiveness assessment methodology should be developed that takes into account the characteristics of market development and innovation trends.

In the analysis of the employer brand level, 5 categories were also distinguished. As a result of the analysis, the corresponding score was 3.91, which was assessed as good. This is an indicator that the company is an attractive employer (Table 1).

Table 1.
Evaluation criteria for employer brand based on average score

Average score range	Level	comment
1.00 – 1.80	Very poor	Company is not attractive as an employer
1.81 – 2.60	Poor	Potential for recruiting staff is low
2.61 – 3.40	Average	Employer brand is in the process of formation
3.41 – 4.20	Good	Company is an attractive employer
4.21 – 5.00	Very high	Strong employer brand exists

The four main criteria of this indicator were evaluated separately. The attractiveness of the company as an employer was rated at 3.93 points, the prestige of the company as a workplace was rated at 3.82 points, the ability to attract qualified personnel was rated at 3.97 points, and the recommendation of others as a workplace was rated at 3.9 points (Figure 3).

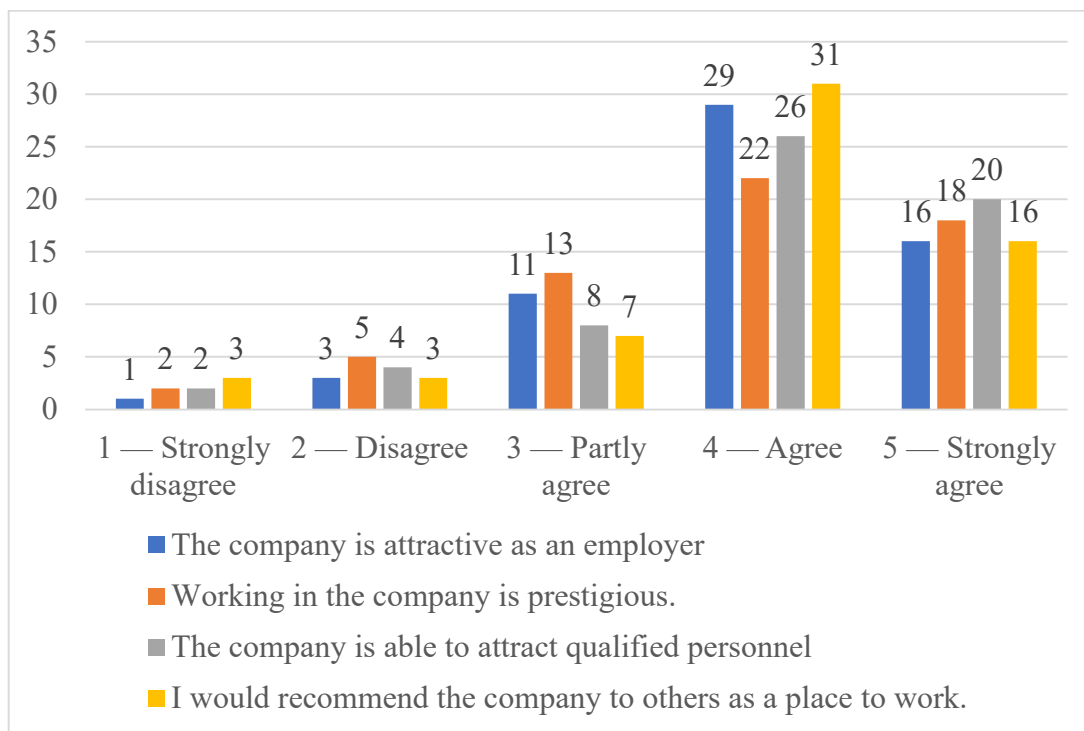


Figure 3. Employer Brand, with people

When assessing the level of competitiveness of the company, 5 categories were also identified. When analyzing these criteria, the indicator was higher at 4.03, but the company was also assessed as good according to this indicator. This indicates the existence of competitive advantages (Table 2).

Table 2
Criteria for assessing the company's competitiveness based on the average score

Average score range	Level	comment
1.00 – 1.80	Very low	Competitiveness is weak
1.81 – 2.60	Low	Company has a weak position in the market
2.61 – 3.40	Average	Competitiveness is stable
3.41 – 4.20	Good	Competitive advantages exist
4.21 – 5.00	Very high	Sustainable competitive advantage exists

When assessing the company's competitiveness, it was evaluated as being more competitive than its competitors with 3.97 points, the stability of its market position with 4.02 points, sustainable development with 4.12 points, product and service quality with 4.08 points, and the competitive advantage of human resources with 3.9 points (Figure 4).

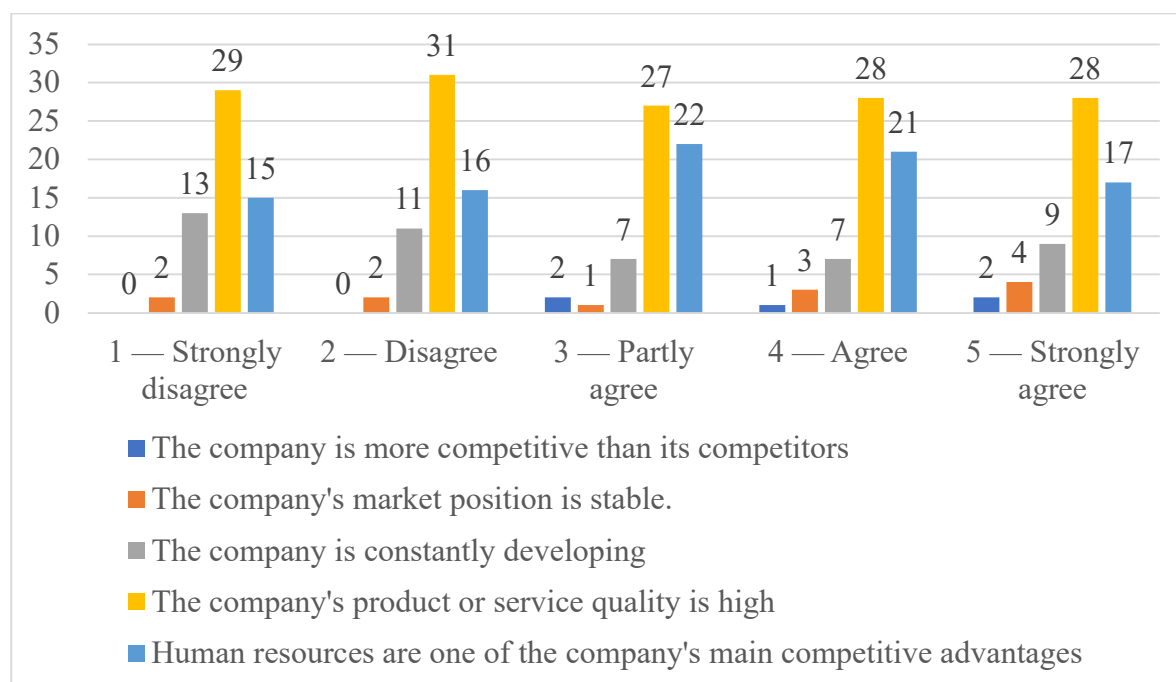


Figure 4. Company Competitiveness, in people

The high average scores at a similar level indicate the existence of an interaction between leadership brand, employer brand, and company competitiveness. Strengthening the leadership brand has a positive impact on the attractiveness of the employer brand, which in turn has a positive impact on the company's competitiveness (Table 3).

Table 3.
Company brand and competitive assessment

Variable	Average score	Level	Comment
Leadership Brand	3.91	Good	Leadership brand is effective
Employer Brand	3.91	Good	Company is an attractive employer
Competitiveness	4.03	Good	Competitive advantages exist

The development of branding requires the solution of such theoretical and methodological issues as the justification of a systematic approach to brand management, the identification of branding functions, and methods for building effective brand-consumer relationships. This necessitates the development of recommendations for the selection of branding activities, as well as methods for researching products on the market, ensuring consumer awareness, and selecting advertising sources for new and existing brands. Another criterion for the transformation of a product into a brand is the introduction of innovations that indirectly benefit the brand by strengthening its market position. At the same time, the benefits obtained through innovation acquire real value and generate income for companies. Analyzing the development of the most well-known brands that have been on the market for several decades, it can be concluded that many of them are serious innovators. By introducing a new invention or significantly modernizing and modernizing an existing one, the brand becomes not only a "mechanism" for becoming a well-known and profitable brand, but also a stimulant of social development and scientific and technological progress.

Conclusion. The analysis showed that the company's employer brand had an average score of 3.91 points and competitiveness had an average score of 4.03 points, which corresponds to the "good" level in both areas. The existence of a correlation with the leadership brand indicates that strengthening the employer brand has a positive effect on the company's competitiveness. These results confirm that systematic management of branding activities and innovative approaches

strengthen the company's market position. The study also emphasizes the importance of methodological proposals for forming a brand for products and services and achieving a leading position in the market.

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THE EFFECTIVENESS OF MODERN PROJECT MANAGEMENT TOOLS IN SOCIAL MEDIA MANAGEMENT

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Abstract. In recent years, social media management has transformed from a primarily creative activity into a complex operational system requiring structured coordination, speed, and accountability. The growth of multi-platform strategies, increasing content volume, and rising expectations for measurable performance have made project management tools an essential component of digital marketing workflows. This article examines the effectiveness of modern project management solutions in the context of social media management, with particular attention to their practical application across major social platforms. The study analyzes how contemporary tools support planning, production, approval, and performance optimization processes, identifies their advantages and limitations, and evaluates their real-world effectiveness under platform-specific constraints. Based on professional experience and industry analysis, the paper outlines which approaches currently deliver the highest operational value and defines future directions for project management systems in social media marketing.

Keywords: project management, social media management, digital marketing operations, workflow optimization, platform governance.

Introduction. Social media has become one of the most dynamic and resource-intensive areas of modern marketing. Brands, agencies, and independent professionals now operate within an environment characterized by continuous content production, real-time audience interaction, rapid trend cycles, and frequent platform updates. As a result, the management of social media activities increasingly resembles a production system rather than a traditional marketing function. In this context, project management tools are no longer used solely for long-term planning or internal coordination; instead, they function as operational frameworks that enable marketing teams to maintain consistency, speed, and quality across platforms.

Unlike early-stage social media workflows that relied on informal coordination and manual scheduling, contemporary practices demand structured pipelines that integrate content ideation, asset creation, approval processes, publication coordination, and post-publication analysis. This shift has led to widespread adoption of project management software originally designed for general business or software development purposes, now adapted for marketing and social media operations. The purpose of this article is to assess whether these tools genuinely improve efficiency and effectiveness in social media management and to determine under which conditions they provide measurable value.

Methodological Approach

The analysis presented in this paper is based on a qualitative evaluation of contemporary project management platforms widely used by marketing teams in 2025–2026. The assessment combines three perspectives: a review of current professional literature and industry reports, an examination of official platform documentation related to publishing and automation limitations, and applied professional experience accumulated over more than ten years in project management and social media strategy.

Rather than focusing on technical specifications alone, the evaluation emphasizes operational outcomes such as workflow clarity, coordination efficiency, reduction of errors, and the ability to adapt quickly to changing platform requirements. Particular attention is paid to how project management tools interact with social media platforms' policies, application programming interfaces, and content governance rules, as these factors significantly influence real-world effectiveness.

Project Management Tools as Operational Systems for Social Media

Modern social media management involves a continuous cycle of activities that includes content planning, creative production, multi-level approvals, scheduling, community engagement, and performance review. In practice, operational failures rarely occur due to a lack of ideas or creative talent; instead, they arise from fragmented communication, unclear responsibilities, disorganized feedback, and delays caused by inefficient coordination.

Project management tools address these issues by providing centralized environments where tasks, deadlines, assets, and feedback are structured and traceable. When implemented effectively, such systems reduce cognitive load for team members, standardize recurring processes, and allow managers to identify bottlenecks early. However, their effectiveness depends heavily on how well they are aligned with the realities of social media work, which is iterative, time-sensitive, and often reactive.

Tools that are overly rigid or complex can slow down content production and discourage adoption among creative teams. Conversely, systems that are too flexible may lack governance, leading to inconsistency and loss of accountability. The balance between structure and adaptability is therefore a critical determinant of success.

Platform Constraints and Their Impact on Project Management Effectiveness

The effectiveness of project management tools in social media marketing cannot be evaluated independently of platform-specific constraints. Each social network imposes its own technical, policy, and operational limitations, which directly affect how workflows must be designed.

On visually driven platforms such as Instagram, content production is heavily asset-based, requiring coordination of video, imagery, captions, and metadata. While project management tools significantly improve version control and approval tracking, publishing workflows are influenced by limitations imposed by official publishing interfaces and automated posting rules. These restrictions necessitate careful planning and compliance-aware processes within project management systems.

In contrast, short-form video platforms prioritize speed and volume, rewarding teams that can rapidly test and iterate content. In such environments, lightweight project management structures that support fast feedback loops tend to outperform heavily layered approval systems. Overly complex workflows can reduce responsiveness and negatively impact performance.

Professional networking platforms emphasize content quality, credibility, and consistency. Here, project management tools demonstrate strong effectiveness by supporting structured editorial planning, expert review, and long-term content strategies. Governance and accountability are particularly valuable in these contexts, as reputational considerations are paramount.

Long-form video platforms introduce additional complexity due to extended production cycles, higher resource investment, and stricter content policies. In these cases, project management tools provide substantial value by coordinating multi-stage production processes, ensuring compliance, and maintaining predictable publishing schedules.

Real-time communication platforms present unique challenges related to automation rules and policy enforcement. While project management systems are effective for escalation

management and response coordination, they are less suitable for direct automation and must be used cautiously to avoid policy violations.

Comparative Effectiveness of Contemporary Tools

Across the current landscape, the most effective project management solutions for social media management share several characteristics. They allow customization of workflows without excessive technical overhead, support collaboration through contextual feedback, integrate with external storage and publishing systems, and provide visibility into workload and timelines.

Tools that combine task management with documentation and reporting capabilities tend to perform well in marketing environments, particularly when teams seek to reduce the number of disconnected systems they use daily. Platforms designed with strong visual representations of work are especially effective for non-technical stakeholders and cross-functional teams.

However, no single tool can fully address all aspects of social media management. The highest-performing organizations typically rely on integrated ecosystems, where a project management platform functions as the coordination layer, while specialized tools handle publishing, analytics, and community engagement. The project management system, in this model, serves as the backbone that aligns strategy, execution, and learning.

Comparative Analysis of Project Management Tools in Social Media Management

Project Management Tool	Best-Suited Social Platforms	Operational Advantages	Operational Limitations	Overall Effectiveness in Social Media
ClickUp / monday.com	Instagram, Facebook, TikTok	High flexibility, customizable workflows, strong visual planning	Risk of over-configuration, learning curve	High for multi-platform content operations
Asana / Wrike	LinkedIn, YouTube, Facebook	Clear governance, structured approvals, accountability	Less flexible for rapid iteration	High for professional and regulated content
Jira / Smartsheet	YouTube, integrated campaigns	Advanced tracking, reporting, scalability	Limited creative workflow support	Moderate to high in enterprise environments
Trello / Notion	Instagram, Pinterest, early-stage brands	Ease of use, fast adoption, low overhead	Limited scalability and governance	Moderate for small teams

Future Directions and Most Effective Approaches

Current trends indicate that the future of project management in social media marketing lies not in increasing complexity, but in improving alignment between tools, processes, and platform realities. Artificial intelligence features, such as automated summaries and predictive insights, are becoming more common, yet their value depends on the presence of clear underlying processes.

From an operational perspective, the most effective approach in 2026 is a hybrid model that combines structured project management with platform-specific expertise and flexible execution. Organizations that define clear workflows, establish ownership, and continuously adapt

their systems to platform changes achieve higher consistency, faster turnaround times, and better performance outcomes.

Rather than searching for a universal solution, social media teams benefit most from selecting tools that match their scale, content velocity, and regulatory environment. Effectiveness is ultimately determined not by software capabilities alone, but by how well those capabilities are embedded into disciplined, human-centered workflows.

Conclusions

This study demonstrates that modern project management tools play a significant role in improving the efficiency and reliability of social media management when applied thoughtfully. Their greatest value lies in reducing coordination friction, standardizing recurring processes, and enabling teams to operate at the speed required by contemporary platforms. At the same time, platform-specific constraints and policy changes limit the extent to which automation and standardization can be applied.

The most effective solutions in current practice are not isolated tools, but integrated operational systems that balance structure with adaptability. As social media continues to evolve, project management tools will remain essential components of digital marketing infrastructure, provided they are used as enablers of clarity and collaboration rather than sources of administrative burden.

STRATEGIC MODELS FOR COMMERCIALIZING INNOVATIVE LABORATORY DIAGNOSTIC METHODS

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Abstract. This article presents a strategic model for commercializing new laboratory diagnostic methods, using niche methods for assessing mitochondrial function as an example. Based on an analysis of successful cases (Mitome, Jinfinity, My NAD Test) and regulatory practices (FDA, IVDR), the critically important stages of the transition from a scientific prototype to a marketable product were detailed, namely, clinical validation, intellectual property protection, regulatory registration, and insurance coverage. It was also found that the key factor for market success is not technological superiority, but the comprehensive synchronization of the scientific, legal, and economic components of the project. This model can serve as a practical guide for researchers and entrepreneurs in the field of biomedicine.

Keywords: commercialization, laboratory diagnostics, regulatory approval, reimbursement, mitochondrial diagnostics.

Introduction and problem statement.

Modern healthcare is undergoing a profound transformation driven by demographic aging, the growing burden of chronic diseases, and the rapid development of biomedical technologies [1]. This context creates an urgent need to transition from reactive medicine to personalized and preventive medicine, where modern laboratory diagnostic methods play a key role. Methods for assessing the fundamental biological processes of aging [2], especially non-invasive methods (as opposed to traumatic procedures such as biopsies), are of particular interest to science and clinical practice. Therefore, the development of methods for assessing mitochondrial function represents a significant scientific breakthrough in real clinical practice [10]. However, there is a deep gap, known as the "valley of death" of translational medicine [8], on the path to making these diagnostic methods widely available to patients.

The first level of problems is technological and market-related. The global in vitro diagnostics (IVD) market, which reached approximately \$112 billion in 2024 [3], is showing steady growth. The most dynamic segments are molecular diagnostics, point-of-care (PoC) testing, and home testing, which meet the demands for speed, accuracy, and accessibility. Despite this, the commercialization of advanced diagnostic solutions remains a high-risk and capital-intensive

endeavor. According to experts at Boston Consulting Group (BCG), even companies with product revenues in excess of \$100 million may spend more than 100% of their revenues on research, development (including clinical evidence collection), and marketing, remaining unprofitable for many years. A key obstacle is the need not only to prove the analytical accuracy of the test, but also to convincingly demonstrate its clinical utility, namely how the test results influence medical decisions and improve patient outcomes, which is a prerequisite for acceptance by the medical community and payers.

The second, equally complex level of challenges is regulatory and economic. The regulatory landscape is tightening, particularly in the European Union with the introduction of the IVDR regulation, which raises the bar for clinical evidence. In the United States, uncertainty remains regarding the future of laboratory-developed tests (LDTs) [6], which have historically been the primary route for bringing innovations to market. At the same time, as noted in the scientific literature, even in the area of regulator-approved companion diagnostics, barriers to innovation are emerging, including market fragmentation due to multiple tests for a single biomarker, high cost, and complexity of interpretation, which ultimately limits patient access to optimal testing. The key factor determining the fate of any diagnostic product is ensuring reimbursement. Obtaining payment codes from insurance companies and government systems, such as Medicare in the United States, is a complex, multi-step process that requires strong health economics data and strategic engagement with payers.

The purpose of this article is to develop a comprehensive, step-by-step strategy for translating an innovative laboratory diagnostic method (using the example of mitochondrial assessment) into a commercially viable product in the in vitro diagnostics (IVD) market. To achieve this goal, the following research questions are addressed sequentially in this paper:

1. What are the key, universal stages in the commercialization of a life cycle of a diagnostic method, from scientific discovery to market entry?
2. What specific economic (monetization models, unit economics, attracting investment) and regulatory (FDA/IVDR approval, obtaining CMS reimbursement codes) factors are critical at each of these stages?
3. What business models and market entry strategies have proven effective, as confirmed by analysis of successful case studies of leading companies (such as Guardant Health in liquid biopsy or Exact Sciences in colorectal cancer screening)?

Thus, this study aims to create a practical foundation that will combine the scientific potential of new diagnostic developments with the stringent requirements of the modern medical technology market, helping to accelerate the introduction of innovations for the benefit of the aging population's health.

Materials and methods.

The study uses a systematic review methodology, supplemented by a comparative case study analysis and an analysis of market trends in the field of biomedical developments. The empirical and analytical basis of the study was provided by scientific publications and industry analytical reports [3, 4], as well as a comparative analysis of business models (case studies). To systematize the stages of the diagnostic technology life cycle, we studied works on translational medicine [8], the Stage-Gate model, and technology readiness levels (TRL). The context of the in vitro diagnostics (IVD) market, its growth in drivers, and trends were analyzed based on industry reports, including data from MedTech Europe [3].

The core of the study was a comparative analysis of the strategies of three key players in the functional diagnostics niche: Mitome [11], Jinfinity [12], and My NAD Test [13]. Their business models were examined using a unified framework (value proposition, scientific basis, monetization, marketing) based on publicly available company materials (websites, marketing

communications, scientific rationale). This analysis allowed us to identify further differentiated approaches to commercialization.

To validate the theoretical model, the commercialization path of the "mitochondrial passport" from [Mitolab.kz](https://mitolab.kz) [14] was reconstructed in detail. Analysis of the sequence of actions (from research and patenting [9] to clinical validation [10], registration, laboratory creation, and marketing) confirmed the applicability of the identified stages in real practice.

Results and discussion.

An analysis of successful and unsuccessful cases in molecular diagnostics shows that the commercialization of a diagnostic discovery usually follows the universal Stage-Gate logic, which correlates with technology readiness levels (TRL). At the first stage, corresponding to TRL 1–3, the key is scientific discovery and confirmation of the analytical validity of the test. An example is the development of the [Mitolab.kz](https://mitolab.kz) mitochondrial passport, which began with fundamental research in 2019 on the early diagnosis of socially significant diseases, including the study of the effectiveness of mitochondrial rehabilitation in cervical cancer [16]. At this stage, the concept was proven, the analytical parameters of the method for functional assessment of neutrophils and mitochondrial activity were evaluated, and the results were published in a scientific article [18]. The next stage involved the formation and protection of intellectual property, which in this case was achieved through the acquisition of a utility model patent in 2022 [9]. The prototype development and clinical validation stage (TRL 4–6) was completed sequentially during further research in oncology, including studies of lung cancer [19] and colorectal cancer [17], the results of which were published in the journal *Minerva Medica* in 2025 [10]. At the same time, studies at the International Institute of Postgraduate Education (IIPE) in Almaty were completed and registered with the RNTD, which consolidated the scientific basis of the method [15].

A separate critical block is the selection and implementation of the regulatory route. In the case of [Mitolab.kz](https://mitolab.kz), after registering the research results, the stage of including the mitochondrial passport in the DAR laboratory services registry as a type of general blood test was successfully completed [13]. This allowed the transition to the operational scalability stage, which included the creation of a clinical laboratory within the LNB clinics in 2025 with the appropriate license, where the mitopassport became part of the routine laboratory profile. Commercial success and scaling are impossible without access to payment and product promotion in the market. The project team actively worked to raise awareness among doctors and patients by conducting explanatory work through Saturday meetings, as well as presenting the method at major international venues, such as the Mitologic conference in 2024 [21], nutritionist gatherings, the Russian Congress of Clinical and Medical Oncology in Sochi, and the oncology and dermatology conference in Vienna [22, 23]. Despite initial ignorance and skepticism on the part of some of the medical community, active scientific and educational activities, backed up by publications and patents, have changed attitudes towards the method [20]. Thus, the [Mitolab.kz](https://mitolab.kz) mitochondrial passport project illustrates in practice how the consistent completion of the stages of scientific justification, patent protection, clinical validation, regulatory approval, infrastructure creation, and aggressive marketing can lead to the successful commercialization of even a complex diagnostic solution in a market initially characterized by mistrust.

Analysis of successful cases and lessons learned.

The analysis allows us to identify three differentiated commercialization strategies, each of which demonstrates adaptation to the specifics of the target audience and product.

Criterion	Mitome	Jinfiniti	My NAD Test
Product essence	Comprehensive analysis of mitochondrial function and a personalized optimization plan.	NAD+ level test and program to increase it.	Home test kit for determining NAD+ levels.
Value proposition	Solving energy, digestion, and aging problems at the root, cellular level through accurate measurements.	Control aging and energy through accurate NAD+ data and personalized supplements.	A simple and affordable way to track your NAD+ to understand how your body is aging and whether supplements are working.
Scientific basis	Analysis of >35,000 clinical studies, proprietary algorithm, 1,500 identified optimization pathways.	Use of gold standard laboratory analytics (HPLC, mass spectrometry) and biosensors.	Bioluminescent sensor technology based on jellyfish protein for accurate home testing.
Target audience	People with complex, unexplained health problems (chronic fatigue, arrhythmia, brain fog).	Conscious consumers who are interested in biohacking, longevity, and preventive medicine.	A broad audience aged 30+ interested in healthy aging and simply wanting to start tracking their metrics.
Commercialization	High price point, high value: a \$699 kit that includes in-depth analysis and a personalized plan.	Expanded product portfolio: from tests to branded supplements (Vitality↑®) and a comprehensive aging panel (AgingSOS®).	Standardized product: focus on a convenient, single-use home test kit with the goal of repeat purchases.
Marketing	Success stories and word of mouth: detailed reviews with health transformations that build deep trust.	Educational content: detailed guides, links to research, positioning as an expert.	Simplicity and acute pain: emphasis on "3 easy steps," clear graphics, call to immediate action.

Mitome (mito.me) positions its service as an in-depth diagnostic solution for complex cases that cannot be explained within the framework of traditional medicine [11]. Its value proposition focuses on the link between mitochondrial dysfunction and a wide range of symptoms, from chronic fatigue and digestive disorders to cardiac manifestations, which correlate with the understanding of mitochondria as key organelles in cellular energy metabolism [2]. According to the company's materials, its scientific platform is based on the analysis of an extensive array of

clinical data (over 35,000 studies) and proprietary interpretation algorithms. Mitome's economic model falls into the high-price segment (the starter kit costs \$699), which corresponds to its position as a premium service offering not just data, but a comprehensive personal plan for correcting identified disorders. The key marketing asset and driver of trust is the detailed case studies of patients, which create a social proof effect.

In contrast, **Jinfiniti** (jinfiniti.com) builds its strategy around creating an integrated data-driven ecosystem [12]. Its main product is a clinically validated test for intracellular levels of NAD⁺, a coenzyme critical for cellular energy metabolism and aging processes [2]. The focus on "intracellular" measurement, as the company claims, provides a more relevant clinical picture compared to plasma content analysis. Jinfiniti's business model is built on a funnel principle, where the diagnostic test serves as an entry point for the subsequent sale of personalized therapeutic interventions, particularly the proprietary Vitality↑[®] NAD⁺ Booster supplement. Thus, revenue is generated both from diagnostic services and from repeat sales of consumable products, which increases customer lifetime value (LTV). The scaling strategy includes developing a network of partnerships with physicians and offering comprehensive panels for assessing aging, such as AgingSOS[®].

The third model, presented by the **My NAD Test** project (mynadtest.com), is focused on maximizing consumerization and democratizing access to diagnostics [13]. The product is focused on performing a single task—convenient and affordable measurement of NAD⁺ levels at home using bioluminescent sensor technology. The value proposition minimizes complexity in favor of simplicity, clarity, and speed ("3 easy steps"). This strategy targets a broad audience of consumers interested in healthy aging and involves monetization through repeat purchases of test kits to monitor changes in the indicator against the background of taking supplements or changing lifestyle. This model is closer to classic D2C (direct-to-consumer) products in the wellness sector.

Economic lessons learned and success factors.

A synthesis of the analysis of the three cases allows us to formulate a number of general economic principles that contribute to successful commercialization in this sector. First, the transition from selling abstract "technology" to solving a specific, acutely perceived problem is critical [8]. Successful companies identify a clear "pain point" whether it is a diagnostic impasse with complex symptoms, a desire to take control of the aging process [1], or the need to verify the effectiveness of expensive supplements and build their entire value proposition around it. Second, scientific validity and technological reliability are not just a competitive advantage, but a basic condition for product legitimacy and the basis for price premiums. Companies invest in demonstrating their scientific foundation (references to research, descriptions of HPLC/MS methods, CLIA certification of laboratories, as in the case of Jinfiniti) to overcome the natural skepticism of consumers and the medical community.

Third, the most economically sustainable models are designed for long-term, cyclical customer relationships rather than one-time transactions. This is achieved by designing a "closed loop": measurement → personalized recommendation (intervention) → re-measurement to evaluate effectiveness. This approach, which is evident in Jinfiniti's strategy, increases LTV and creates a predictable stream of recurring revenue. Finally, an important lesson is that the business model must be consistent with the chosen market niche [4]. A deep expert model with a high average check (Mitome) is effective for a narrow segment of patients with complex problems. The ecosystem model (Jinfiniti) requires significant initial investment in R&D and validation but opens up opportunities for monetization at several stages of the value chain. The simplified D2C model (My NAD Test) allows for rapid entry into a broad market but may face higher competition and price pressure.

Applied strategy for mitochondrial diagnostics.

Adapting a universal model for commercializing diagnostic technologies to the field of mitochondrial functional diagnostics requires consideration of both the biological object of measurement and the clinical context of the method's application. Unlike static molecular genetic tests, dynamic mitochondrial analysis, including leukocyte functional diagnostics, reflects the current state of cellular metabolism, energy exchange, and immune activation [2]. This determines its greatest practical value in monitoring, risk stratification, and assessment of response to therapy, rather than in one-time nosological diagnosis.

The analysis of the strategic path described above finds its practical embodiment and confirmation in the activities of specific projects. The example of the Kazakh startup [Mitolab.kz](https://mitolab.kz) demonstrates the consistent implementation of key principles of successful commercialization in the field of mitochondrial diagnostics, making it a relevant case for comparison with players such as Mitome, Jinfiniti, and My NAD Test [14].

[Mitolab.kz](https://mitolab.kz), which positions itself as a "Cellular Mitochondrial Laboratory," offers a product called "Mitochondrial Health and Immune Resource Passport." Its development follows the logic outlined in the applied strategy. First, the company focuses on specific clinically relevant scenarios, which is consistent with the principle of prioritizing clinical scenarios. The main areas of application are oncology and rehabilitation, where monitoring mitochondrial function can be critical for assessing treatment tolerance and monitoring recovery processes [16, 17, 10]. Second, the product is structured as a graduated offering starting from basic to complete analysis, including the assessment of 15 key functional indicators, such as the performance of respiratory chain complexes, oxidative stress, and the proportion of active mitochondria. This reflects the approach to forming a Minimal Clinical Product (MCP) with subsequent expansion.

An important element of [Mitolab.kz's](https://mitolab.kz) strategy is to build a partnership network with clinics and doctors, including the provision of specialized online training for medical professionals. This directly contributes to the integration of the method into clinical practice and the formation of trust on the part of the medical community — one of the key tasks in the early stages of commercialization. In addition, the company claims to have its own scientific base, to have tested the methods on more than 6,000 patients, and to have published the results in international journals, which corresponds to the stage of accumulating an evidence base that goes beyond analytical validity [9, 10, 15, 16, 17, 18, 19, 20, 21, 22, 23].

From a business model perspective, [Mitolab.kz](https://mitolab.kz) is likely starting with a format similar to a laboratory-developed test (LDT) [6], performing analysis in its own reference laboratory. Its price positioning (from 40,000 to 150,000 tenge per test) is focused on the Kazakh market and demonstrates a commercial orientation. Thus, the development of [Mitolab.kz's](https://mitolab.kz) Mitopassport on a point scale presents it as a successful startup, comparable to other successful market players. Its trajectory, ncommunity and on clinical scenarios in oncology and rehabilitation, product structuring, active work with the medical community, and building a scientific background clearly illustrates the practical application of a phased strategy for transitioning from a niche LDT to a scalable product in the field of functional mitochondrial diagnostics.

Conclusion.

The commercialization of laboratory diagnostics is a managed, multi-stage process in which scientific novelty is a necessary but insufficient condition for market success. Experience in molecular and oncological diagnostics shows that the key factor in the sustainable introduction of diagnostic technologies is the synchronization of five interrelated aspects: clearly defined clinical value, a convincing evidence base, an appropriately chosen regulatory route [5, 6], access to reimbursement mechanisms [7], and a scalable operating model. An imbalance in even one of

these elements significantly limits the potential of even high-tech and clinically promising solutions [4, 8].

Analysis of successful cases demonstrates that with a properly structured market entry architecture, diagnostic products can generate millions and billions in revenue, as confirmed by the dynamics of leading companies in the field of molecular and oncology diagnostics. These examples emphasize that the economic success of is achieved not through a single test, but through a systematic approach that includes expanding the test menu, increasing volumes, improving gross margins, and gradually achieving a stable operating cash flow.

Regarding mitochondrial functional diagnostics, we can talk about the formation of a favorable window of opportunity. Demographic changes [1], the growing prevalence of chronic and age-related conditions [2], and increased interest in longevity and personalized medicine are creating an objective demand for dynamic methods of assessing cellular and metabolic status. Combined with a focused clinical strategy, step-by-step evidence building, and a realistic monetization model, mitochondrial diagnostics has high potential for economically sustainable implementation in clinical practice and further scaling.

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ИНТЕЛЛЕКТУАЛЬНЫЙ АГЕНТНЫЙ КОМПЛЕКС ДЛЯ АВТОМАТИЗИРОВАННОГО ФИНАНСОВОГО КОНСУЛЬТИРОВАНИЯ И ФИНАНСОВОГО ОЗДОРОВЛЕНИЯ

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В последние годы искусственный интеллект (ИИ) превратился из экспериментального направления в инфраструктурную технологию: рост производительности вычислительных платформ и доступность инструментов анализа данных сделали возможным массовое внедрение машинного обучения в прикладные цифровые сервисы [1]. Финансовый сектор относится к числу наиболее ориентированных на данные отраслей, где ИИ применяется для повышения качества скоринга, прогнозирования рисков и персонализации клиентских продуктов. Параллельно развивается финтех-рынок, формируются цифровые экосистемы и платформенные модели, меняющие способы взаимодействия банков и клиентов [3–5].

Однако активное использование ИИ в финансах сопровождается вызовами: необходимостью управления рисками моделей, обеспечением качества и репрезентативности данных, защитой персональной информации и соблюдением регуляторных требований [2,7,8]. В прикладных задачах финансового консультирования эти ограничения особенно существенны, поскольку ошибки рекомендаций могут приводить к финансовым потерям и снижению доверия пользователей.

Одной из устойчивых социально-экономических проблем остается рост закредитованности и финансового стресса населения. Распространенные цифровые сервисы управления личными финансами преимущественно опираются на транзакционные данные и стандартные показатели долговой нагрузки, тогда как поведенческие причины финансовых затруднений (импульсивные траты, прокрастинация платежей, короткий горизонт планирования, стрессовые реакции) учитываются ограниченно. Это формирует запрос на интеллектуальные решения, которые объединяют финансовую аналитику с инструментами поведенческой экономики и поддерживают пользователя в изменении финансовых привычек.

Целью исследования являлось создание интеллектуального агентного комплекса, предназначенного для автоматизированного финансового консультирования, финансового оздоровления и формирования устойчивого финансового поведения граждан на основе технологий ИИ и поведенческой экономики. Объект исследования – цифровые системы и инструменты, направленные на финансовое консультирование и развитие финансовой устойчивости граждан.

Методологическую основу работы составили системный и междисциплинарный подходы, обеспечивающие комплексный анализ экономических, поведенческих и когнитивных факторов. В исследовании использованы методы применения алгоритмов машинного обучения и математического моделирования для решения задач прогнозирования платежной дисциплины и оценки вероятных сценариев выхода из

состояния закредитованности. Дополнительно применялись принципы поведенческой экономики для проектирования пользовательского пути и механизмов мотивации.

Ключевым результатом исследования стала разработка и апробация прототипа цифровой платформы «Фин Агент», реализующей концепцию интеллектуального агентного комплекса. Платформа предназначена для диагностики уровня закредитованности и финансового стресса, расчета интегральных показателей долговой нагрузки (в том числе DTI – debt-to-income), а также формирования персонализированных рекомендаций по управлению платежами и финансовому оздоровлению. В отличие от решений, ориентированных только на финансовые метрики, платформа опирается на профиль пользователя, включающий поведенческие характеристики и когнитивные факторы, влияющие на соблюдение финансового плана.

Пользовательский сценарий платформы организован как последовательный «квест», что соответствует логике формирования устойчивых привычек через достижимые шаги и регулярную обратную связь. На стартовом экране задается маршрут: удаленная идентификация, диагностика кредитной нагрузки и получение персонального финансового плана (Рисунок 1). В интерфейсе одновременно демонстрируются элементы доверия и безопасности (соблюдение законодательства о персональных данных, защищенный канал передачи), что важно для снижения барьера входа в сервис и повышения готовности пользователя предоставлять сведения для анализа.

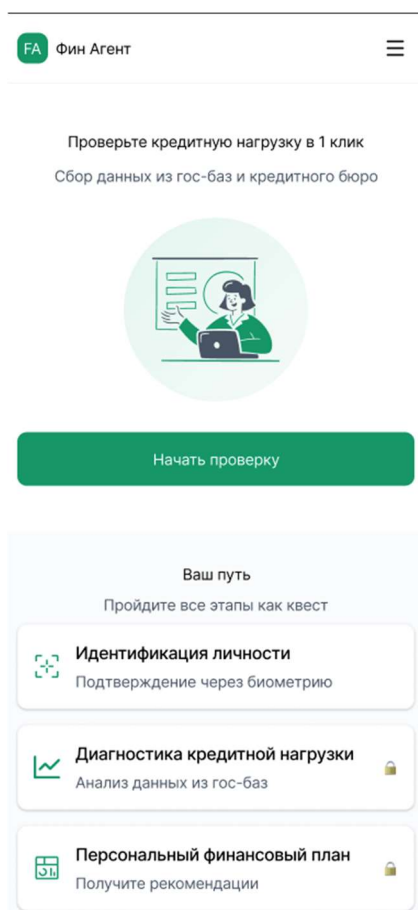


Рисунок 1 – Стартовый экран платформы «Фин Агент» и маршрут пользователя

Следующий этап связан со сбором и обработкой данных из внешних источников. Платформа ориентирована на агрегирование разнородной информации: кредитная история, сведения государственных реестров, а также данные, характеризующие доходы/обязательные отчисления. Концентрация источников в едином контуре позволяет

получить более целостное представление о финансовой нагрузке пользователя и выявлять критические моменты (например, совпадение нескольких платежных дат или потенциально критичную долю обязательных платежей).

Результаты диагностики выводятся в личном кабинете в виде компактной панели состояния: интегральный финансовый рейтинг, показатели долговой нагрузки и риск-профиль, перечень кредитных обязательств, документы и история событий. Такой формат визуализации снижает когнитивную нагрузку и поддерживает интерпретируемость результата: пользователь видит не только оценку, но и ее составляющие, на которые можно воздействовать.

Существенным элементом платформы является геймификация финансового оздоровления. Предусмотрены баллы опыта (XP), бейджи, уровни и визуализация прогресса за выполнение финансовых задач (завершение диагностики, соблюдение графика платежей, ведение бюджета, отказ от импульсивных покупок и др.). Геймификация рассматривается как прикладной инструмент поведенческой экономики: она усиливает мотивацию, делает продвижение по плану наблюдаемым и поддерживает регулярность действий, необходимых для закрепления финансовой дисциплины.

Функциональная архитектура платформы построена по модульному принципу и включает четыре ключевые подсистемы. Подсистема профилирования объединяет анкетные данные, финансовые паттерны и поведенческие характеристики, а также индивидуальные когнитивные факторы, влияющие на финансовые решения. Подсистема прогнозной аналитики использует модели машинного обучения, направленные на прогнозирование платежной дисциплины, оценку вероятности ухудшения финансового состояния и моделирование сценариев выхода из закредитованности (например, реструктуризация, изменение графика платежей, пересборка бюджета). Подсистема нормативно корректного формирования рекомендаций обеспечивает соответствие советов актуальным финансовым нормам, стандартам потребительского законодательства и регуляторным требованиям. Подсистема геймификации поддерживает обучение и закрепление устойчивого финансового поведения.

Платформа предусматривает также рабочее место консультанта: панель мониторинга клиентов, приоритизацию кейсов по уровню риска, историю взаимодействий и отчетность. Такая гибридная модель позволяет автоматизировать типовые консультации с участием ИИ-агента и подключать специалиста к сложным случаям.

Техническая реализация прототипа предполагает клиент–серверную архитектуру и модульный/микросервисный подход. В качестве базового стека определены ExpressJS (BackEnd) и React (FrontEnd); хранение данных планируется в PostgreSQL с возможностью горизонтального масштабирования. Заявленные эксплуатационные требования включают поддержку не менее 5 000 активных пользователей и среднее время отклика на запрос рекомендаций ИИ-агента до 10 секунд при штатной нагрузке. Меры информационной безопасности включают шифрование при передаче (HTTPS/TLS), разграничение прав доступа и аудит действий пользователей; возможна установка в облачной инфраструктуре и/или на серверах заказчика.

Практическая значимость результатов заключается в создании платформенного решения, ориентированного на раннюю диагностику финансовых рисков и формирование персонализированных стратегий финансового оздоровления. Ожидаемый технико-экономический эффект связан со снижением вероятности проблемной задолженности за счет профилактики рисков и автоматизации консультаций, что потенциально уменьшает нагрузку на специалистов и расширяет охват пользователей.

Разработанный прототип платформы «Фин Агент» демонстрирует возможность интеграции ИИ, машинного обучения и инструментов поведенческой экономики в единую

цифровую систему финансового консультирования и финансового оздоровления населения. Дальнейшие исследования целесообразно направить на расширение эмпирической базы данных, оценку эффективности поведенческих интервенций и развитие механизмов объяснимости рекомендаций, повышающих доверие пользователей и устойчивость результатов.

Статья подготовлена по результатам научного исследования в рамках инициативной темы «Интеллектуальный агентный комплекс (ИИ-агента) для финансового оздоровления и формирования устойчивого финансового поведения граждан на основе машинного обучения, поведенческой экономики и нормативно-совместимого автоматизированного консультирования».

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РАЗРАБОТКА ИНТЕГРАЦИОННОЙ ПЛАТФОРМЫ ДЛЯ РЫНКА ЮРИДИЧЕСКИХ УСЛУГ: БИЗНЕС-МОДЕЛЬ И СОЦИАЛЬНО-ЭКОНОМИЧЕСКИЕ ЭФФЕКТЫ НА ПРИМЕРЕ КАЗАХСТАНА

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Введение. Юридическая помощь является критически важным элементом правовой системы и социальной защиты. В Казахстане, как и во многих странах, население и бизнес сталкиваются с постоянной потребностью в квалифицированных юридических услугах, спектр которых охватывает гражданско-правовые, административные, уголовные, семейные, трудовые и корпоративные вопросы [1]. Однако процесс поиска и выбора подходящего специалиста сопряжен со значительными трудностями: отсутствием централизованной информации, временными затратами на анализ предложений, непрозрачностью ценообразования и несистематизированными данными о репутации и опыте юристов [2]. С другой стороны, сами юристы и адвокаты сталкиваются с проблемами привлечения клиентов, высокой стоимостью маркетинга и необходимостью детализации заказов.

В этой связи актуальность разработки единой интеграционной цифровой платформы, решающей указанные проблемы, приобретает не только практическое, но и социально-экономическое значение. Такая платформа способна стать катализатором повышения эффективности рынка юридических услуг, обеспечивая его цифровизацию, прозрачность и доступность. Целью данного исследования является разработка концепции и механизма функционирования единой системы интеграции информации о юридических услугах в Казахстане с возможностью подбора специалистов в разных отраслях юриспруденции.

Методология и анализ рыночных предпосылок

Исследование опиралось на применение общенаучных методов, включая систематизацию и обработку информации, анализ, синтез и индукцию. Объектом исследования выступила единая интеграционная информационная система о юридических услугах в Казахстане, а предметом – область разработок в индустрии LegalTech и вопросы создания специализированных интеграционно-аналитических сервисов.

Анализ предпосылок для создания платформы позволил сгруппировать ключевые проблемные факторы рынка:

1. Информационная асимметрия и временные затраты: Клиенты вынуждены тратить значительное время на поиск специалиста, при этом отсутствует информация о его текущей загруженности и актуальных отзывах.
2. Непрозрачность ценообразования: Рынок характеризуется широким разбросом цен на однотипные услуги. Например, стоимость услуг по регистрации ТОО варьируется от 5 000 до 50 000 тенге [3]. Цена формируется под влиянием множества факторов (опыт, сложность дела, репутация, регион, тип услуги), что затрудняет для клиента объективную оценку стоимости.

3. Отсутствие единой системы верификации и рейтингов: В Казахстане нет общедоступной системы, агрегирующей подтвержденные данные об образовании, специализации, опыте работы юристов, а также отзывы клиентов.

Исследование определяет целевую аудиторию платформы, включающую:

- Физические лица (практически все 20 млн жителей РК в возрасте 18-60 лет), сталкивающиеся с необходимостью правовой помощи в семейных, жилищных, трудовых, наследственных и иных вопросах.
- Юридические лица (более 410 тыс. действующих организаций на март 2023 г.), нуждающиеся в бизнес-сопровождении, судебной защите и корпоративном консалтинге [4].
- Специалисты (юристы и адвокаты), заинтересованные в эффективном канале привлечения клиентов и инструментах для управления своей практикой.

В результате исследования разработана концепция маркетплейса «Zan.Bar», представляющего собой двустороннюю цифровую платформу. Ее основная функция – систематизация данных для поиска и подбора юристов и адвокатов.

Механизм реализации сервиса включает последовательную цепочку действий:

1. Размещение заявки: Пользователь описывает свою правовую ситуацию в стандартизированной форме.
2. Оповещение специалистов: Система автоматически рассылает уведомления юристам, соответствующим критериям запроса.
3. Получение предложений: Заинтересованные юристы направляют клиенту свои предложения с указанием стоимости и условий в течение короткого времени (в идеальной модели – за 3 минуты).
4. Выбор и заключение договора: Клиент сравнивает предложения и выбирает специалиста, после чего стороны могут заключить договор в электронном виде.
5. Исполнение услуг и контроль: Платформа предоставляет инструменты для контроля статуса дела, обмена документами и коммуникации.
6. Оценка и формирование репутации: По завершении работы клиент оставляет отзыв и оценку, которые формируют рейтинг специалиста.

Ключевые конкурентные преимущества разработанной модели включают:

- Скорость и удобство: Сокращение времени поиска и найма юриста до минимума.
- Прозрачность: Четкое отображение цен, статусов дел и истории взаимодействий.
- Управление репутацией: Внедрение системы верифицированных отзывов и рейтингов.
- Инструменты для профессионалов: Возможность безопасного хранения документов, использования шаблонов и аналитики спроса.

Проведенное исследование демонстрирует высокую практическую значимость и коммерческий потенциал интеграционной платформы для рынка Казахстана. Разработка адресует фундаментальные дисфункции рынка юридических услуг, предлагая цифровое решение, которое создает ценность для всех участников.

Для клиентов (B2C и B2B сегменты) платформа обеспечивает значительное снижение транзакционных издержек на поиск, сравнение и выбор специалиста, повышает предсказуемость стоимости услуг и снижает риски, связанные с выбором некомпетентного исполнителя. Это напрямую способствует повышению доступности квалифицированной юридической помощи для широких слоев населения и малого бизнеса.

Для профессионального сообщества (B2P сегмент) платформа выступает как эффективный канал дистрибуции услуг и инструмент цифровизации практики. Платформа решает проблемы маркетинга и привлечения «теплых» клиентов, предоставляет

структурированный рабочий процесс и механизм построения цифровой репутации, что особенно важно для молодых специалистов.

Макроэкономический и социальный эффект проекта заключается в повышении общей эффективности правового поля страны. За счет стандартизации, прозрачности и ускорения процессов оказания юридических услуг платформа может способствовать повышению правовой грамотности, сокращению сроков разрешения споров и, как следствие, улучшению инвестиционного климата.

Потенциал коммерциализации проекта основан на масштабируемой бизнес-модели маркетплейса. Основными источниками доступа могут стать комиссия с успешно заключенных сделок, платные подписки для юристов на расширенные возможности профиля (продвижение, аналитика), а также платные услуги для бизнеса (корпоративный доступ, API-интеграции). Учитывая объем целевой аудитории (миллионы физических лиц и сотни тысяч юридических лиц и специалистов), проект обладает значительным потенциалом роста и трансформации всего рынка LegalTech в Казахстане. Дальнейшее развитие должно быть направлено на интеграцию с государственными информационными системами, внедрение технологий искусственного интеллекта для первичного анализа заявок и расширение перечня услуг (например, онлайн-консультации, документооборот).

Статья подготовлена по результатам научного исследования в рамках инициативной темы «Разработка единой системы по интеграции информации о юридических услугах в Казахстане с возможностью подбора специалистов в разных отраслях юриспруденции».

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Technical Sciences

Compressive Behaviour of Modified Polymeric Aggregate Concrete: An Empirical Modelling

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ABSTRACT

Waste tyres are one of the most significant environmental nuisances the world has to contend with today due to their non-biodegradability in nature. The traditional indiscriminate methods employed in disposing of these waste materials constitute serious environmental hazards and are severely threatening our health, safety and environment. Therefore, recycling these waste tyres into construction materials serves as a suitable means to properly dispose of this vast amount of used rubber tyres. This work, therefore, presents a comprehensive review of the engineering properties of recycled waste rubber tyres. used for reinforced composite concrete production in civil infrastructural works. The experimental research method was adopted in this study, where composite concrete of grade 25 in a nominal mix of 1:2:4 with varying proportions of the polymeric chips as partial replacement to coarse aggregates, ranging from 5%, 10%, 15%, 20%, 30%, up to 60% were used to produce concrete cubes of 150 x 150 x 150mm as specimens and subjected to slump test, and compressive strength test, in order to determine the workability, strength and structural integrity of the concrete. The result of this experiment showed that replacing 5% of natural aggregates with polymeric material in concrete production improved its compressive strength by 3.1% at 7 days of curing and 3.5% at 28days of curing. However, with further increment of the polymeric material to 10%, 20% and above, the compressive strength reduced drastically below the minimum permissible levels. It is hereby recommended that to produce a sound composite lightweight concrete with improved compressive strength for structural stability, a moderate percentage, precisely less than 10% of this polymeric material should be used as partial replacement.

Keywords: Recycled Polymeric Material, Reinforced Concrete, Material Sustainability, Concrete Composite, Compressive Strength, Stress-Strain Behaviour

1. INTRODUCTION

With the development of the automotive industry, tyres have become an integral part of our everyday life and are being used daily, and in different spheres of transportation. However, after being used, these tyres become great nuisance in our environment because they are non-biodegradable [1]. Waste tyre is one of the most significant environmental hazards the world has to contend with, as a result of the increase in automobile production [2]. There is a great need to properly dispose of this vast amount of used rubber tyres for a cleaner Environment. The available sites for waste disposal are rapidly depleting, and several countries have already outlawed the retention of waste rubber tyres in disposal areas. Hence, efforts are being made to discover the

prospective use of waste tyre rubber in the construction industry, and here, rubber crumbs and chips are being considered to be potential materials for use in concrete technology [3,4].

The use of recycled waste tyres as a constituent for reinforced concrete in Civil Engineering applications is based upon their unique characteristics, which include: their lightweight compared to conventional aggregates (coarse or fine) in concrete, good insulation properties, very high ability to resist water, durability and high compressibility due to their elasticity [5,6].

In an effort to improve the durability and resilience of concrete, efforts have made to use recycled rubber tyres for concrete mix, and the results have been positive, stating this mix can help extend the lifespan of concrete structures, road pavements, bridges, as well as providing a convenient method of these wastes [7], [8], [9]. Subjecting this concrete containing polymeric materials to compressive test and also predicting the creep behaviour of this concrete is very important for engineering designs, especially the advanced reinforced composite concrete materials. The term creep describes the phenomenon that the deformation of a material increases with time under constant stress and temperature [10,11]. Creep- Strain is conventionally defined as the difference between the dimensional changes of a stressed specimen and an unstressed specimen irradiated under identical conditions [12]. The apparent strength of concrete is affected by the rate at which it is loaded. In general, for static loading, the faster the loading rate, the higher the indicated strength [13]. The increase in polymeric waste material generation (plastic and rubber) in the world led to the need to develop suitable methods to reuse these waste materials and decrease their negative effects by simple disposal into the environment [14]. Combustion and landfilling, as traditional methods of polymer waste elimination, have several disadvantages, such as the formation of dust, fumes, and toxic gases in the air, as well as pollution of the underground water resources [15]. From the point of energy consumption and environmental issues, polymer recycling is the most efficient way to manage these waste materials [16]. In the case of rubber recycling, the waste rubber can go through size reduction, and the resulting powders can be melted and blended with thermoplastic resins to produce thermoplastic elastomers (TPE) compounds [17]. Recycling is a key component of modern waste reduction and is the third component of the “Reduce, Reuse, and Recycle” waste hierarchy. It promotes environmental sustainability by removing raw material input and redirecting output in the economic system [18]. There are some ISO standards related to recycling, such as ISO 15270:2008 for plastic waste and ISO 14001: 2015 for environmental management control of recycling practice [19].

In this study, different samples of reinforced composite concrete made of polymeric materials shall be subjected to compressive tests to find a suitable material combination that serves as an alternative or an additive to the natural stone aggregate for reinforced composite concrete with durability, strength and structural stability, which are in limited supply. The research also aims to provide an avenue for waste recycling, a way of turning waste into wealth creation for humanity.

2. THEORETICAL FRAMEWORK

Concrete, like any other material, is subject to expansion, contraction, and elastic deformation [20]. The elastic deformation or failure of concrete under continuous loading uses the modulus of elasticity model as the governing equation, where the modulus of elasticity, E , is given in Equation (1):

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\epsilon} \quad (1)$$

Where E is the Young's modulus, σ and ϵ are the applied stress and corresponding strain, respectively [20]

2.1 Mechanical Properties of Polymeric Concrete

The Mechanics of Polymer Concrete (PC) rely on the polymer resins acting on the binder between aggregates, undergoing polymerization (Chemical reaction) to form a hardened, strong composite material. Unlike conventional concrete, which uses cement hydration. This polymerisation creates a vast void-free structure with high strength, chemical resistance and good adhesion [21]. The Mechanical response properties of polymer materials cover a variety of important physical behaviours exhibited under the influence of external load [22].

This indicates how much a material can be stretched, and fully recover its original shape after releasing the external load. The stress-strain relationship describes how much a material deforms (strain) in response to an applied force (stress), and it is characterised by a stress-strain curve

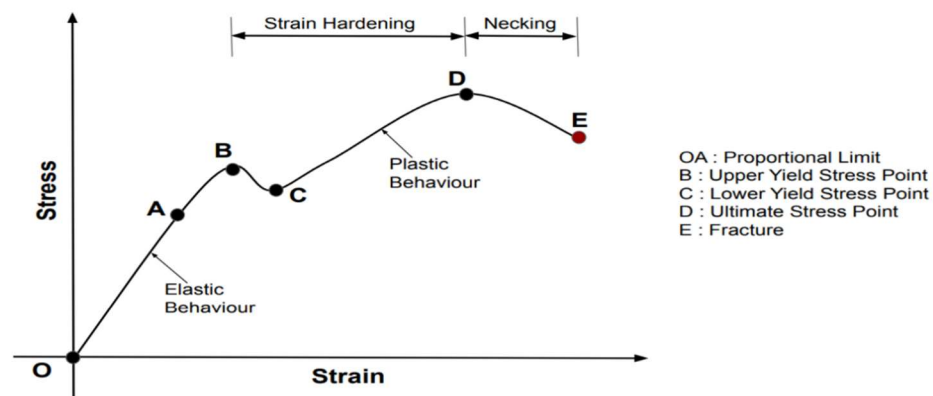


FIG. 1: Stress-Strain Curve [20]

The stress-strain curve reveals the material's mechanical properties, and this relationship starts with a linear, elastic region, from point O to A. At point B, the deformation is reversible. C is the strain hardening zone, D is the fracture zone, and E represent the fracture point where the deformation is permanent. This is governed by Hooke's Law, which states that, provided the elastic limit is not exceeded, the deformation of a material is directly proportional to the force applied to it [23]. This relationship is expressed by the equation:

$$F_s = -kx \quad (2)$$

Where: F_s = Spring Force (N)
 k = Spring Constant (N/m)
 x = Spring Stretch or Compression (m)

The minus sign indicates that the restoring force acts in the opposite direction to the displacement and is always trying to return the object to its original position [24]. It simply shows that the strain of a material is proportional to the applied stress within the elastic limit of the material.

3. MATERIALS AND METHODS

This work is basically to verify the workability and compressive strength of the Concrete with partial replacement of polymeric materials, specifically recycled waste rubber tyres as an alternative or additive to the conventional fine and coarse aggregates in composite concrete.

3.1 Applied Method

The Experimental Research Method was adopted using polymeric material as a partial replacement to natural coarse aggregates for the production of composite concrete, which was subjected to compressive strength test in the laboratory to determine its strength and structural integrity.

3.2 Techniques of Data Collection and Analysis

The waste rubber tyres were hewed into chips and crumbs and produced reinforced composite concrete with varying proportions of the polymeric chips as replacement to natural coarse aggregates, ranging from 5%, 10%, 15%, 20%, 30%, up to 60%. These were subjected to Slump test, and compressive strength tests to determine their workability and yield strengths under varying magnitudes of loads according to the variables obtained from the reinforced concrete material specimens, at various mix proportions and mix ratios.

3.3 Experimental Mix Design

The target design Concrete for this work was grade 25 concrete with the mix ratio of 1: 2: 4 B.S standard using Portland Cement, Natural Sea Sand as fine aggregates, Crush Rock with partial replacement of polymeric materials as coarse aggregates and potable water. The percentage composition of polymeric materials to natural coarse aggregates is as shown below:

C. max = Pure Natural Coarse aggregates only

Rc.5 = 5% replacement of polymeric materials to coarse aggregates

3.4 Selection of Materials:

The materials used for this work include: Portland cement Class 42.5 of BSI, Natural sea sand of 0.45 to 4.75mm, Crush Rock (chippings) of 5 to 20mm, Potable water, and Rubber chips from waste tyres shredded into 5mm to 20mm diameter



Fig. 2: Heap of waste tyres

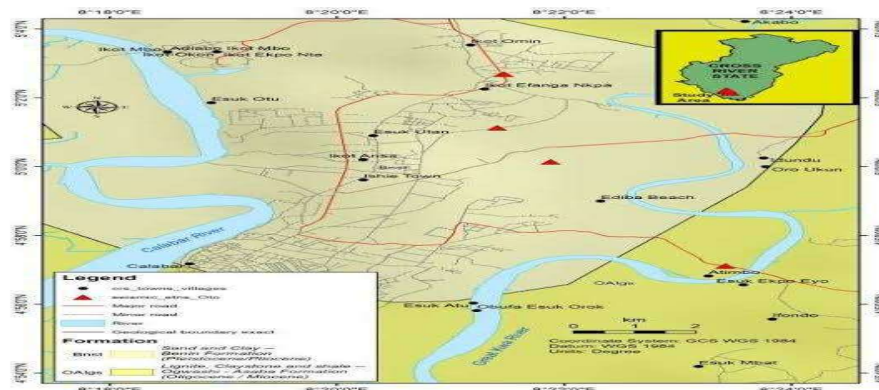


Fig. 3: Map of Tyre dump site, Esuk Utan, Calabar Municipality



Fig. 4: Shredded Rubber Chips from waste tyres

Figure 4: Showing a heap of rubber chips, already chopped and shredded into different sizes of 4.75 to 15.0mm from waste tyres to be used as partial replacement to coarse aggregates in composite concrete mix.

3.5 Slump Test

Slump test is a widely used method to measure the workability of a fresh concrete. It is a test that measures how much freshly mixed concrete settles when a mold is removed.

Equipment to conduct the Slump Test include:

Slump Cone of (300mm height, 100mm Top diameter and 200mm Bottom diameter, Tamping Rod of (600mm length and 16mm diameter), Concrete mixing bucket, head pan, shovel and Trowel, Measuring Tape/ Ruler, Mold of (150mm x150mm), Calibrated water Jar, and Recording book

3.6 Test Preparation

- i. The slump Cone was well cleaned and moisten to receive fresh concrete
- ii. A representative sample was collected from the freshly mixed concrete
- iii. The slump Cone was filled with the freshly mixed concrete sample in three layers, each of 100mm high and appropriately compacted.

3.7 Testing Procedure

- i. The tamping rod was used to compact each layer of concrete inside the cone and 35 strokes were applied to each layer to ensure even spreading on the surface
- ii. The tamping rod was also used to level and smooth the top surface of the concrete
- iii. The slump cone was carefully removed vertically without shaking or disturbing the concrete.

- iv. The distance from the Top of the cone to the Top of slumped concrete after removing the cone was measured and recorded
- v. This process was repeated with different samples of fresh concrete mix with rubber chips at different proportions of 5%, 10%, 15%, 20%, 30%, 40%, 50% and 60% respectively. And the results were recoded accordingly as shown in table 1



Fig. 5: Slump measurement

Figure 5 shows the freshly mixed concrete, removed from the cone and placed side by side with the cone to measure the level of fall for the determination of the slump test.

Table 1: Experimental Test of Concrete mixed with Rubber chips

S/N	Specimen Designation	Natural Aggregate (Kg) (%)	Polymeric Material (Kg) (%)	Cement (Kg) %	Natural Sea Sand (Kg) (%)	Potable Water (L)
1	C _{max}	100	0	100	100	2
2	Rc.5	95	5	100	100	2
3	Rc.10	90	10	100	100	2
4	Rc.15	85	15	100	100	2
5	Rc.20	80	20	100	100	2
6	Rc.30	70	30	100	100	2
7	Rc.40	60	40	100	100	2
8	Rc.50	50	50	100	100	2
9	Rc.60	40	60	100	100	2

Table 2: Slump Test of Concrete mixed with Rubber chips

S/N	Specimen Designation	Natural Aggregate (Kg) (%)	Polymeric Material (Kg) (%)	Slump (Mm)
1	C _{max}	100	0	282
2	Rc.5	95	5	281
3	Rc.10	90	10	279
4	Rc.15	85	15	277
5	Rc.20	8	20	275
6	Rc.30	70	30	273
7	Rc.40	60	40	270
8	Rc.50	50	50	265
9	Rc.60	40	60	260

3.8 Compressive Strength Test

Compressive strength test measures the strength of the concrete and is one of the most common tests used to verify the quality of concrete. It is a type of mechanical testing that involves applying a compressive force to a material and measuring its response. The compressive force tends to reduce the size of the material, and the test is designed to determine the behaviour of the material under the type of load applied.

The compressive strength is the maximum compressive load that the cube can carry per unit area and is calculated as shown in equation 3.

$$F_{Cu} = \frac{P_{max}}{A} \quad (3)$$

Where,

- F_{Cu} = Compressive strength (N/mm²)
- P_{max} = Magnitude of failure load (N)
- A = Cross-sectional area of the cube specimen (mm²)

3.9 Equipment to conduct Compressive Strength Test

Compression Testing Machine (which consists of a load cell, a Crosshead, Compression test tools and an electronic recorder), Cube Moulds, Curing Tank, and Weighing Machine

Cover/door



Fig. 6: Compression testing Machine with concrete cube

Figure 6 shows the Compressive strength testing machine with the door widely open and made up of applied load, the regulator, the soft weir counter, the bottom plate to hold the cube in place and the concrete cubes ready for crushing.

3.10 Test Preparation for Compressive Strength

- i. Removal of the cubes (specimen) from the water where they were immersed for 7days and 28days curing
- ii. Plug and Set up the crushing machine
- iii. Positioning the specimen
- iv. Setting up test parameters
- v. Pre-loading and pre-conditioning Compressive test execution
- vi. Data collection for Analysis.

3.11 Procedure for Conducting Compressive Strength Testing

During the compressive test, a sample or specimen of the material (Cube) was first weighed in a weighing machine, and the value recorded, and then the cubes were placed in a crushing machine where they were compressed between two plates. The machine applies a gradually increasing load to the specimen, and the change or deformation in the dimension of the material increases at various points until it begins to fail or deform permanently. This process was repeated with different samples of concrete cubes mixed with rubber chips at different proportions of 5%, 10%, 15%, 20%, 30%, 40%, 50% and 60% respectively. The exercise was conducted on the 7th day and on the 28th day with the specimen designation.

4. RESULTS AND DISCUSSIONS

4.1 Slump Test

From the slump test conducted to determine the workability and consistency of the concrete mix using natural coarse aggregates in addition to the partial replacement of polymeric materials to produce a composite concrete, the following results were obtained:

1. **Slump Values:** The Slump value is the difference between the height of the concrete before the cone was removed and after the cone was removed and is usually measured in millimetres (mm). The height of the Cone minus the height of freshly moulded concrete after carefully removing the Cone:

A, (C. max): For Concrete with only natural aggregates without additives

B. (RC.): For Concrete mix with natural and rubberised aggregates

$$F_2 = F_1 - F_0 \quad (4)$$

Where F_2 is the height of the Cone filled with freshly moulded concrete (mm)

F_1 is the height of the moulded concrete after removing the cone (mm)

F_0 is the level of slump after removing the cone (mm)

Table 3: Result of Slump Test of Concrete mixed with Rubber Chips

S/N	Specimen Designation	Natural Aggregate (Kg) (%)	Polymeric Material (Kg) (%)	Slump Value (mm)
1	C _{max}	100	0	18
2	Rc.5	95	5	19
3	Rc.10	90	10	21
4	Rc.15	85	15	23
5	Rc.20	80	20	23
6	Rc.30	70	30	27
7	Rc.40	60	40	30
8	Rc.50	50	50	35
9	Rc.60	40	60	40

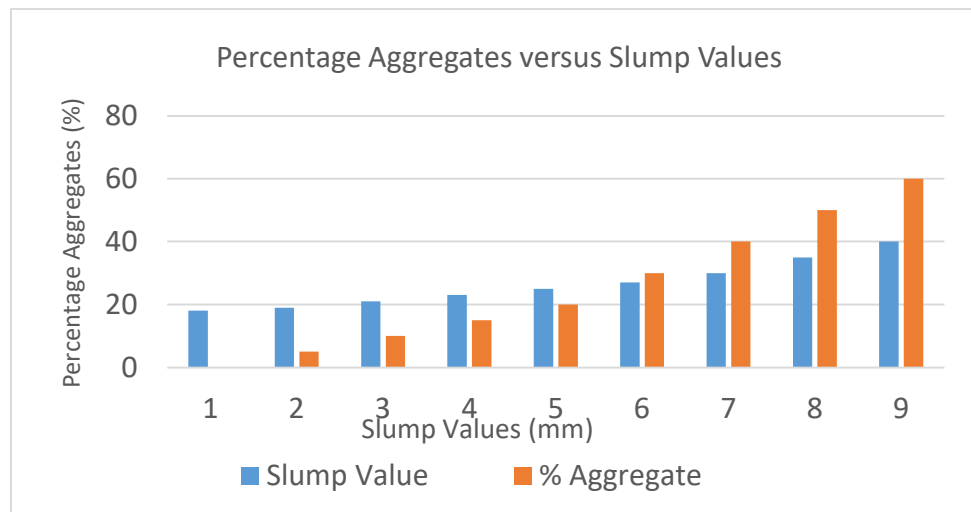


FIG.7: Percentage Aggregates versus Slump Values

Figure 7 indicates the Bar Chart of the Percentage Aggregates versus Slump Values as obtained from the slump test, showing the blue bar representing the slump value and the yellow bar representing the percentage rubberised aggregates used. At 100% natural aggregates and 0% rubber chips, the slump value is 18cm, while at 5% replacement with rubber chips, the slump increased to 19cm. with further increment of the polymeric material to 60%, the slump value increased to 40cm, showing a very high workability.

4.2 Compressive Strength Test

Compressive strength test measures the strength of the concrete and is used to verify the quality of the concrete. It is the maximum compressive load that the cube can carry per unit area before failure

From the compressive strength test conducted on the 7th day of curing, the results were obtained and used for the calculations as shown in Equation 5.

$$F_{Cu} = \frac{P_{max}}{A} \quad (5)$$

Where,

F_{Cu} = Compressive strength (N/mm²)

P_{max} = Magnitude of failure load (N)

A = Cross-sectional area of the cube specimen (mm²)

Table 4: Result for Compressive Strength Test of concrete at 7days

S/N	Specimen Designation	Natural Aggregate (Kg) (%)	Polymeric Material (Kg) (%)	Weight Of Cube (G)	Compressive Strength (Mpa)
1	C.max	100	0	7902	17.46
2	Rc.5	95	5	7662	17.73
3	Rc.10	90	10	7638	16.92
4	Rc.15	85	15	7428	16.54
5	Rc.20	80	20	7420	13.00
6	Rc.30	70	30	7360	10.47
7	Rc.40	60	40	7203	8.08
8	Rc.50	50	50	6874	6.93
9	Rc.60	40	60	6502	5.72

FIG. 8: Percentage Aggregates Vs Compressive Strength at 28days curing

Figure 8 indicate the bar chat of Percentage aggregates versus Compressive Strength conducted after 7 days Curing, showing that for the mixture with 100% natural aggregates and 0% rubber chips, the compressive strength of the concrete is 17.5Mpa. and at the replacement of the natural aggregates with 5% polymeric materials, the compressive strength increased to 17.7%. But with further increment of rubber chips to 10%, the strength decreases to 16.9%

From the compressive strength test conducted on the 28th day curing, the result was obtained and used for the calculations as presented in equation 6.

$$F_{Cu} = \frac{P_{max}}{A} \quad (6)$$

Where, F_{cu} = Compressive strength (N/mm²)

P_{max} = Magnitude of failure load (N)

A = Cross-sectional area of the cube specimen (mm²)

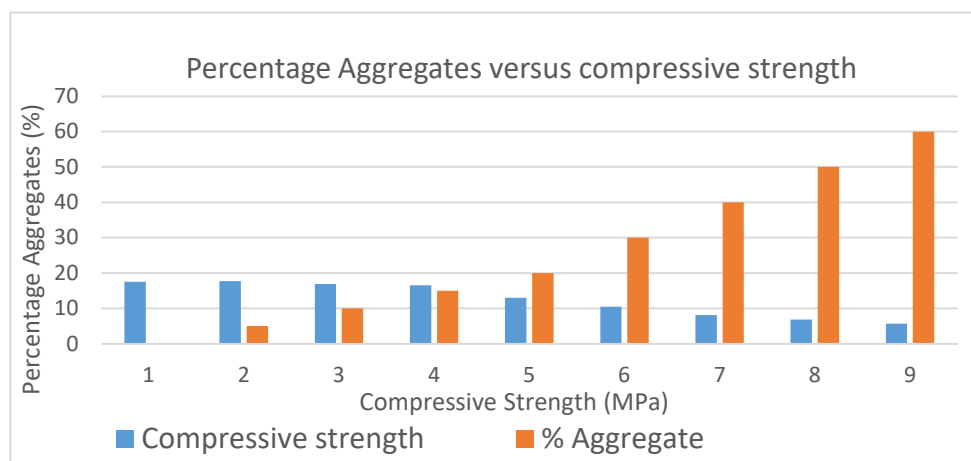


Table 5: Result of Compressive Strength Test of concrete at 28days

S/N	Component	Polymeric Aggregates (kg) (%)	Compressive Strength (MPa)
1	C. max	0%	17.8
2	Rc.5	5	18.1
3	Rc.10	10	17.0
4	Rc.15	15	16.7
5	Rc.20	20	13.3
6	Rc.30	30	11.8
7	Rc.40	40	8.4
8	Rc.50	50	7.2
9	Rc.60	60	6.2

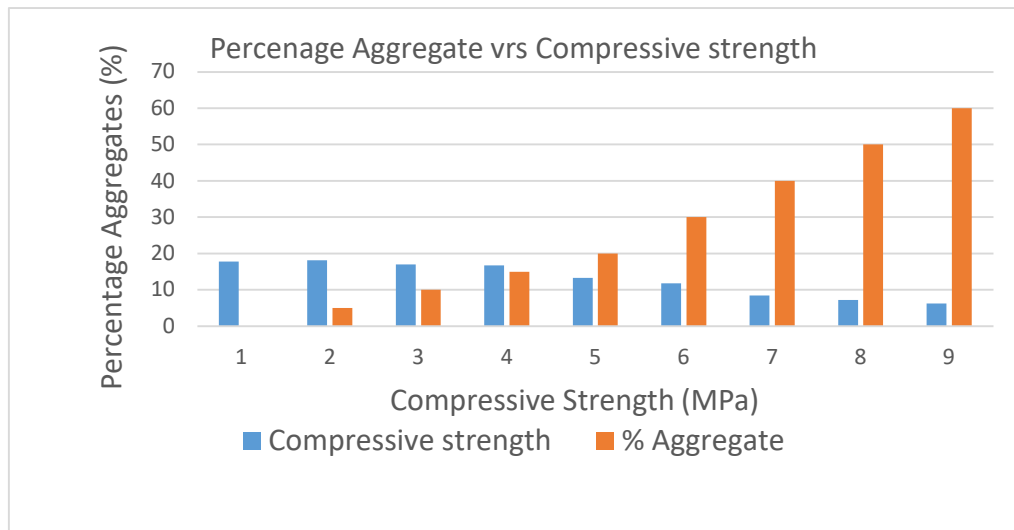


FIG. 9: Percentage Aggregates Vs Compressive Strength at 28days curing

The result of the compressive strength test conducted showed that the conventional Concrete mix without any addition of rubberized chippings has a compressive strength of 17.5MPa while the specimen mixed with a replacement of 5% rubber chips is 17.7MPa, signifying an increase in compressive strength of 1.2%. But with further increment in the replacement of natural aggregates with rubberized chips, from 10%, 15%, 20%, 30% up to 60%, the compressive strength decreased drastically to 16.9MPa, 16.5MPa, 13.0MPa and down to 5.7MPa respectively, indicating a corresponding percentage decrease in strength of 3.4%, 5.7%, 25.7%, 40% down to 67.4% for 7th day curing. While the test conducted at 28th day curing showed a compressive strength of 17.8MPa of the conventional concrete without any admixture. And the specimen mixed with 5% polymeric material replacement had a compressive strength of 18.1MPa. Also with increment of polymeric material replacement to 10%, 15%, 20%, 30% up to 60%, the strength reduced to 17.0MPa, 16.7MPa, 13.3MPa, 11.8MPa down to 6.2MPa. This signifies a reduction in strength from 1.7% to 4.5%, 6.2%, 25.3%, 33.7% down to 65.2%, respectively.

5. CONCLUSION

The use of recycled waste tyres as a constituent for reinforced concrete in Civil Engineering applications is based upon their unique characteristics which include: their lightweight compared to conventional aggregates (coarse or fine) in concrete, good insulation properties, very high ability to resist water, durability and high compressibility due to their

elasticity. In an effort to improve the durability and resilience of concrete, it has become very necessary to use recycled rubber tyres for concrete mix and the result is positive, This work is basically to verify the workability and compressive strength of the Concrete with partial replacement of polymeric materials, specifically recycled waste rubber tyres as an alternative or additive to the conventional fine and coarse aggregates in composite concrete. Different samples of reinforced composite concrete made of polymeric materials were subjected to compressive test to find a suitable material combination that serves as a replacement to the natural stone aggregate for reinforced composite concrete which are in limited supply. This study also found a convenient means of eliminating the challenge of the disposal of waste tyres in our environment since they are non-biodegradable and occupy much space in landfills, and Ocean dump. The research also provided an avenue for waste recycling, a way of wealth creation for sustainable development.

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Comparative analysis of flood monitoring information systems

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Against the backdrop of global climate transformations and the increasing frequency of extreme meteorological phenomena, floods are becoming one of the most widespread and destructive natural disasters. According to the World Meteorological Organization, in the period from 2000 to 2023 the consequences of floods affected more than 1.5 billion people, which allows them to be regarded as the predominant type of natural hazard [1]. Overflowing water masses have a significant negative impact on economic systems, infrastructure facilities, and the agricultural sector, and also pose a direct threat to the life and health of the population. In this regard, the implementation of modern digital solutions becomes particularly important, including machine learning methods and artificial intelligence technologies that ensure increased forecasting accuracy and reduced response time [2]. Floods are among the most large-scale in terms of consequences and regularly recurring natural disasters worldwide. According to information from the World Meteorological Organization (WMO), over the past decades there has been a noticeable increase in both the frequency and the intensity of floods, including in territories that were not previously considered high-risk areas [3]. Climate transformations, urbanization processes, disruption of natural ecosystems, and inefficient water resource management contribute to the growing vulnerability of territories and populations to flood and inundation events. It is projected that by 2050 the number of people living in areas of potential flood risk may more than double [4]. This problem is most pronounced in countries characterized by extensive river systems, mountainous terrain, and densely populated lowland areas. The Republic of Kazakhstan also belongs to the group of vulnerable states, as seasonal flood events and emergency situations caused by intense rainfall, rapid snowmelt, and river overflow are recorded annually on its territory. For example, during the spring periods of 2017 and 2023, large-scale floods were documented in several regions of Kazakhstan, resulting in the evacuation of a significant number of residents, damage to infrastructure facilities, and substantial economic losses [5]. Traditional approaches to flood monitoring and response are often characterized by delays and insufficient accuracy of results, as they are based on outdated technological solutions, are susceptible to human factors, and have limited capacity to account for large volumes of real-time information. Under conditions of accelerating natural process dynamics and the growing number of data sources (satellite imagery, meteorological indicators, sensor networks, and IoT devices), the need for the development of automated monitoring systems is increasing, ensuring the rapid collection, processing, and analytical interpretation of information for timely managerial decision-making [6]. The development of artificial intelligence technologies, machine learning methods, and Big Data analytics tools creates fundamentally new opportunities for solving the tasks of automated flood detection and forecasting. Intelligent algorithms are capable of effectively identifying hidden

relationships within heterogeneous data streams and adapting to changing operating conditions in real time [7]. The application of such technological solutions contributes to improving the accuracy of predictive assessments, reducing the response time of emergency services, and ultimately ensuring a decrease in human casualties and the minimization of socio-economic damage.

Review of existing information systems for flood monitoring and analysis The Copernicus Emergency Management Service (CEMS) is a specialized component of the European Copernicus programme aimed at monitoring, impact assessment, and information support for emergency response, including floods [8]. This service provides satellite observations, analytical materials, and cartographic products used both for operational response and for the strategic planning of risk-reduction measures. The coordination of CEMS activities is carried out by the European Commission with the participation of the European Space Agency (ESA), the European Centre for Medium-Range Weather Forecasts (ECMWF), and other European Union institutions. The service tools are used by governmental bodies, humanitarian organizations, United Nations agencies, and the International Committee of the Red Cross [9].

Main components of CEMS

The CEMS service operates in two main areas of activity:

Rapid Mapping - an emergency mapping mode that involves the production of cartographic materials within 6–24 hours from the moment of activation. This tool is used for rapid assessment of the extent of flooded areas, planning evacuation measures, and documenting the damage caused.

Risk & Recovery Mapping - a direction focused on long-term risk analysis, preparation of infrastructure facilities for potential emergency situations, and strategic planning for sustainable land use.

A notable example of CEMS effectiveness was its deployment in 2021 following large-scale floods in Germany and Belgium. Within several hours, radar images of inundated zones were obtained, and within a day interactive damage maps were produced with a level of detail down to individual streets [10].

Data sources and technological framework. Within the CEMS framework, a wide range of satellite and auxiliary geospatial data is utilized, in particular:

- Sentinel-1 (SAR) - radar imagery that enables data acquisition regardless of cloud cover and time of day;
- Sentinel-2 - high-resolution optical imagery;
- Landsat, TerraSAR-X, SPOT, Pleiades - commercial and open-source remote sensing data sources engaged depending on monitoring tasks and scenarios;
- digital elevation models, land-use information, and climatic parameters used to improve the accuracy of analytical calculations.

The processing of incoming information is carried out using automated algorithmic tools, including computer vision and machine learning methods, followed by expert verification of the results by specialists of the European Union Satellite Monitoring Centre.

Formats and products

As part of its activities, the CEMS service generates and distributes the following types of information products:

- Reference Maps - baseline cartographic materials created prior to the occurrence of an emergency event and used as the initial spatial reference;
- Flood Delineation Maps - maps that display the boundaries and extent of flooded areas;
- Grading Maps - analytical maps reflecting the degree and nature of the damage caused;
- reporting materials and geospatial datasets in GeoTIFF and Shapefile formats intended for subsequent download and processing in geographic information systems.

All information resources are published on the official emergency.copernicus.eu portal, and access to the data is provided free of charge.

The key advantages of the CEMS service include:

- Timeliness - the generation of initial cartographic materials is typically carried out within 6–12 hours after request activation;
 - High accuracy - spatial resolution reaches approximately 10 m for radar (SAR) data and up to 2.5 m for optical imagery;
 - Scalability - the system is capable of processing territories of varying coverage levels, from individual settlements to national boundaries;
 - Openness - data are provided free of charge and without usage restrictions;
- Interoperability - support for formats compatible with widely used geoinformation platforms, including ArcGIS, QGIS, and Google Earth.

The practical effectiveness of the toolset was demonstrated, in particular, in Mozambique in 2019 after the passage of Cyclone Idai, when CEMS was used to identify a flooded area exceeding 2,000 km². The obtained data contributed to the rapid distribution of international humanitarian aid and the reduction of the risk of repeated losses [8].

Comparative analysis of flood monitoring information systems

Effective flood monitoring organization involves the use of integrated information systems that ensure rapid data collection, analytical processing, and clear visualization of heterogeneous information. In international practice, the most widespread platforms are CEMS (European Union) and GFMS (NASA), while in the Republic of Kazakhstan predominantly basic national solutions are in operation, currently undergoing phased digital modernization [12].

Conducting a comparative analysis of these systems makes it possible to identify their key differences, common functional elements, and promising areas of integration that can be taken into account when developing intelligent monitoring platforms adapted to the natural-climatic and infrastructural conditions of Kazakhstan.

Approaches to Architecture and Data Sources

Table 1 — Comparative characteristics of flood monitoring systems: CEMS, GFMS, and national platforms of the Republic of Kazakhstan

Characteristics	CEMS	GFMS	Казахстан
Data Source	ESA satellites, digital maps, requests	NASA satellites, GPM/TRMM models	Ground stations, sensors, partially satellites
Access	On request	Open access	Partially open
Update Frequency	6–24 hours	Every 3 hours	1–7 days
Resolution	2–10 m	~12.5 km	Point-based values

International platforms are characterized by a higher level of automation in information-processing procedures and greater spatial data detail, rely on global satellite observation sources, and provide analytical results in open access [13]. At the same time, the currently operating national solutions of the Republic of Kazakhstan are largely based on manual data input, the use of fragmented sensor nodes, and insufficiently integrated geoinformation tools

Functionality and Practical Application

Table 2 — Comparative analysis of the functional capabilities of flood monitoring systems: CEMS, GFMS, and the national platform of the Republic of Kazakhstan

Function	CEMS	GFMS	Kazakhstan
Monitoring	+	++	limited
Forecasting	partially	+++	–
GIS visualization	+++	++	point-based
Archives	available	since 2000	in PDF

In terms of functional capabilities and applicability to the strategic planning of flood-prevention measures, the GFMS and CEMS systems demonstrate the highest effectiveness. At the same time, their use without prior localization and adaptation to regional conditions significantly limits their practical efficiency.

National Systems of the Republic of Kazakhstan

Advantages: consideration of regional specifics and direct accessibility for профильные governmental emergency services; Limitations: insufficient implementation of artificial intelligence methods, weak integration with geoinformation platforms, and a significant share of manual data input and processing.

Adaptation and Integration Opportunities for Kazakhstan

The conducted comparative analysis indicates that none of the considered platforms, in isolation, provides a comprehensive solution to the flood-monitoring task. A promising direction is the formation of a hybrid architecture that combines the potential of international services with local information sources and regional characteristics [55]. The following practical steps may be considered:

- integration of GFMS and CEMS data into national information systems;
- connection of satellite WMS/API services to the interfaces of authorized emergency management bodies;
- creation of a centralized archive of historical flood and inundation data;
- implementation of machine-learning algorithms for forecasting and early-warning tasks.

A positive example of such integration is demonstrated by the Republic of Uzbekistan, where since 2021 a model combining CEMS data with local hydrological stations has been piloted, which increased the accuracy of flood forecasting by approximately 30% [56].

Conclusion

International platforms such as CEMS and GFMS provide a high level of automation in information processing and advanced visualization capabilities, whereas existing Kazakhstani solutions require digital and analytical modernization [57]. The synergistic integration of international technological tools with national data and institutional mechanisms can form the foundation for building an intelligent, adaptive, and effective flood-monitoring system in the Republic of Kazakhstan.

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ИННОВАЦИОННАЯ ЦИФРОВАЯ ПЛАТФОРМА ДЛЯ ДИСТАНЦИОННОГО ДОСУДЕБНОГО КОЛЛЕКТИВНОГО УРЕГУЛИРОВАНИЯ ЗАДОЛЖЕННОСТИ

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Современный финансовый сектор Казахстана сталкивается с системной проблемой: процедуры досудебного урегулирования просроченной задолженности и реструктуризации долгов во многих организациях остаются фрагментарными, бюрократизированными и слабо контролируемыми. Коммуникации между кредитором и заёмщиком часто ведутся через разнородные каналы, обращения клиентов обрабатываются вручную, а согласование условий реструктуризации занимает недели и месяцы. В результате возрастают кредитные риски, увеличиваются расходы на персонал и документооборот, усиливается социальное напряжение, а часть кейсов переходит в судебную плоскость.

Международная практика показывает, что цифровые механизмы онлайн-разрешения споров (Online Dispute Resolution, ODR) позволяют сокращать сроки и стоимость урегулирования, а также повышать доступность процедур для граждан и организаций [1–4]. В исследованиях последних лет подчёркивается потенциал алгоритмической поддержки (в том числе методов машинного обучения и обработки естественного языка) для классификации обращений, подготовки предложений и прогнозирования сценариев урегулирования [1,3,10]. Одновременно фиксируются риски непрозрачности и предвзятости алгоритмов, что требует этических рамок, аудита и сохранения ключевой роли человека в принятии решений [5,9,12].

Целью настоящего исследования стало внедрение инновационной цифровой платформы для дистанционного коллективного урегулирования задолженности, обеспечивающей юридически значимый электронный документооборот, обмен документами и контроль статусов обращений в режиме реального времени. Объектом исследования выступила веб-платформа «Kelisim Bar», ориентированная на автоматизированное взаимодействие заёмщиков и финансовых организаций (включая микрофинансовые организации) при проведении медиации и согласовании реструктуризаций.

Методологически работа опиралась на междисциплинарный подход, объединяющий правовой анализ, принципы цифровой трансформации и методы системного проектирования. На этапе аналитического обзора были рассмотрены подходы к цифровизации досудебных процедур и цифровому документообороту, включая вопросы юридической силы цифровых коммуникаций и хранения доказательств [2,7]. Проведён сравнительный анализ с рядом рыночных решений, показавший, что многие продукты ограничиваются консультационным сопровождением или формированием документов без механизмов юридической фиксации и без интеграций с официальными источниками данных. Сформированные выводы легли в основу функциональных и технических требований к разрабатываемой платформе.

Ключевой результат научно-технической деятельности — разработка программно-технологического комплекса «Kelisim Bar», обеспечивающего полный цикл

досудебного урегулирования: от подачи обращения до заключения и фиксации соглашения. Платформа реализует два пользовательских контура: административный (для сотрудников кредитных организаций) и клиентский (для заёмщиков). Сценарии взаимодействия описаны как управляемые бизнес-процессы (workflow), где каждое действие имеет статус, временную метку и сохраняется в журнале операций, что формирует проверяемую «историю дела».

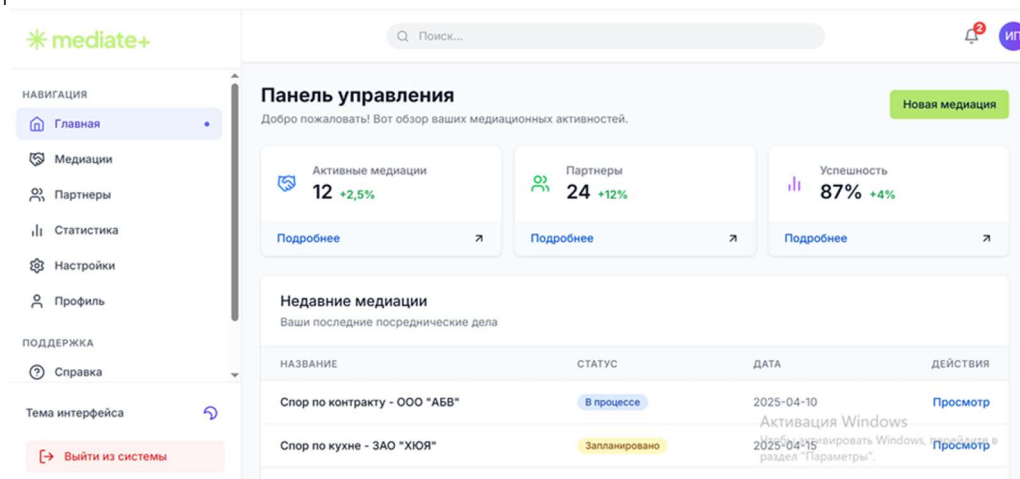


Рисунок 1 – Панель управления администратора (дашборд и недавние медиации)

Административная панель предназначена для обработки обращений и управления коммуникациями с клиентами. Система поддерживает защищённый вход с подтверждением одноразовыми кодами, массовую и индивидуальную рассылку уведомлений, поиск и фильтрацию обращений, формирование и отправку типовых документов (соглашений, графиков платежей), а также мониторинг статусов «отправлено / просмотрено / подписано». Визуализация ключевых метрик (активные кейсы, партнёры, показатели успешности) вынесена в дашборд, что обеспечивает операционную управляемость процесса и позволяет руководителям отслеживать эффективность урегулирования.

Клиентская часть платформы обеспечивает дистанционное взаимодействие заёмщика с финансовой организацией. Авторизация выполняется по номеру телефона с подтверждением через одноразовый код, после чего пользователь может подать обращение по типовым основаниям (например, запрос на пересмотр графика платежей или формирование нового графика), отслеживать статусы и получать документы для подписания. Таким образом, процесс реструктуризации переводится в полностью цифровой формат, сокращая число очных визитов и снижая барьеры участия.

Критически важным элементом является юридически значимый документооборот. Подписание документов реализовано через механизм OTP-подписи: одноразовый код выступает подтверждением волеизъявления стороны, а параметры операции (время, идентификаторы, статус) фиксируются в системе. После подтверждения документ сохраняется как неизменяемый артефакт, а все действия пользователей протоколируются. Такой подход повышает доказательную устойчивость цифровых коммуникаций и соответствует тенденциям развития цифровых процедур урегулирования и электронного правосудия [2, 7].

Для повышения качества решений и снижения ручной проверки «Kelisim Bar» предусматривает интеграцию с национальными источниками данных через шлюз Smart Bridge для получения кредитной информации из официальных каналов. Интеграционный контур обеспечивает достоверность данных о заёмщике и кредитной истории, что важно при формировании реалистичных графиков реструктуризации и оценке рисков. В результате

уменьшается вероятность спорных интерпретаций и повышается доверие между сторонами, что особенно значимо в массовых сегментах микрофинансирования.

Платформа включает встроенную систему аналитики: формирование статистики по успешности процедур, динамике обращений, типам кейсов и нагрузке по партнёрам. Аналитический контур важен не только как инструмент отчётности, но и как механизм обратной связи для управления продуктом и правилами урегулирования: данные позволяют выявлять узкие места процесса, оценивать эффективность шаблонов документов и корректировать коммуникационные сценарии.

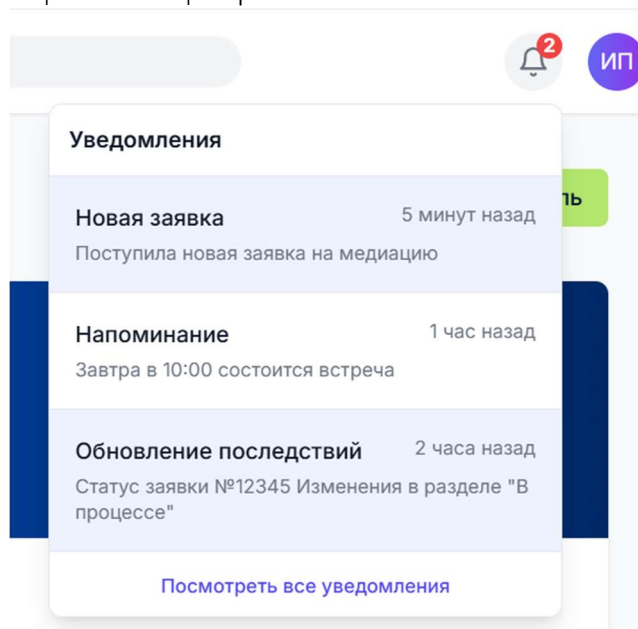


Рисунок 2 – Пример уведомлений о событиях процесса (новая заявка, напоминание, изменение статуса)

Техническая реализация «Kelisim Bar» основана на serverless-архитектуре с использованием облачных сервисов Firebase и фронтенда Single Page Application на React. Подобный технологический выбор соответствует логике цифровой трансформации и платформенных решений: инфраструктура автоматически масштабируется, снижая эксплуатационные затраты и повышая доступность сервиса [6,8]. Коммуникационный слой реализован через SMS-шлюз (Mobizon API), обеспечивающий доставку OTP-кодов и уведомлений. Безопасность поддерживается двухфакторной аутентификацией, правилами доступа на уровне базы данных, шифрованием трафика по HTTPS и логированием действий пользователей.

В ходе тестового внедрения подтверждена работоспособность ключевых сценариев. Система обеспечивает обновление статусов в реальном времени; отправка и получение OTP-кода занимает менее 30 секунд; время загрузки страниц не превышает 2 секунд. Архитектурные параметры допускают масштабирование до 100 000+ одновременных пользователей и обработку до 100 000 SMS-сообщений в сутки при соответствующей конфигурации сервиса. С практической точки зрения это создаёт предпосылки для тиражирования решения на национальном уровне и формирования нового сегмента финтех-услуг — цифровой медиации проблемной задолженности.

С точки зрения платформенной экономики интеграция участников (кредиторов, заёмщиков, медиаторов и финтех-партнёров) в единую цифровую среду способна формировать сетевые эффекты, когда ценность сервиса возрастает по мере расширения круга пользователей [8,11]. В перспективе развитие интеллектуальных модулей (например, автоматическая классификация обращений или рекомендательные подсказки на основе

накопленной статистики) должно рассматриваться как вспомогательный контур, где алгоритмы поддерживают специалиста, но не подменяют решение человека [10,12].

Таким образом, разработанная платформа переводит досудебное урегулирование задолженности из разрозненных ручных процедур в унифицированный цифровой процесс, обеспечивая прозрачность, юридическую значимость и ускорение взаимодействия сторон. Ожидаемый эффект выражается в снижении нагрузки на суды и финансовые организации, ускорении реструктуризаций и повышении доверия между кредиторами и заемщиками. Дальнейшие исследования целесообразно направить на расширение интеграций, развитие аналитических моделей и формирование регуляторных и этических механизмов, обеспечивающих безопасное применение алгоритмической поддержки в финансовой медиации [5,9].

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ИНДУСТРИАЛЬНЫЙ ПАРК КАК ИНСТРУМЕНТ ЛОКАЛИЗАЦИИ ПРОИЗВОДСТВА СВАРОЧНОГО ОБОРУДОВАНИЯ: КЕЙС ЗАПАДНОГО КАЗАХСТАНА

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Западный Казахстан, будучи стратегически важным регионом с доминирующей ролью нефтегазового сектора, формирует устойчивый спрос на сварочное оборудование, расходные материалы и услуги высокоточной механической обработки [1]. Интенсивное развитие нефтепереработки, трубопроводного строительства и смежных отраслей сопровождается высокими требованиями к объемам, качеству и оперативности поставок. Однако существующая промышленно-производственная и логистическая инфраструктура региона не в полной мере отвечает этим потребностям, что приводит к значительной импортозависимости и связанным с ней логистическим и ценовым рискам.

Мировая практика демонстрирует растущий тренд на локализацию (reshoring) критически важных производств, направленный на повышение устойчивости цепочек поставок, снижение операционных рисков и стимулирование технологического развития регионов [2]. В этом контексте создание специализированного промышленного парка представляется стратегически обоснованным решением для Западного Казахстана. Целью данного исследования является комплексное обоснование создания системы Industrial Park Atyrau, направленной на локализацию полного цикла производства сварочного оборудования и сопутствующих услуг для промышленного сектора.

1. Методология и аналитическая основа исследования

Методологическую основу работы составил комплексный подход, включающий:

- SWOT-анализ для оценки сильных и слабых сторон проекта, а также внешних возможностей и угроз.
- Ландшафтный аудит промышленно-производственной и логистической инфраструктуры Западного Казахстана.
- Технологический анализ современных линий производства сварочных материалов, оборудования и механообработки.

Объектом исследования выступил промышленный парк как специализированная площадка для интегрированного производства и механической обработки.

2. Анализ потребностей и потенциала локализации

Анализ текущего состояния региона выявил наличие стабильного, но циклического спроса со стороны нефтегазовых и инфраструктурных предприятий на сварочные материалы (электроды, проволоку, флюсы) и услуги по изготовлению запасных частей. При этом локальные мощности не обеспечивают полного покрытия потребностей, а reliance на импорт влечет за собой удлинение сроков поставки, рост затрат и уязвимость к внешним шокам.

Сравнительный анализ международного опыта (Китай, Канада, Европа) показал, что эффективная локализация достигается за счет синергии государственных стимулов (налоги, требования по местному содержанию), целевых инвестиций в инфраструктуру и привлечения технологических партнеров [3, 4]. Для сектора сварочных материалов и механообработки это сулит прямые преимущества: сокращение логистических издержек и времени доставки, повышение оперативной ремонтпригодности оборудования и возможность кастомизации продукции под местные стандарты.

3. Результаты: концепция и оценка проекта Industrial Park Atyrau

Результатом исследования стала концептуальная модель Industrial Park Atyrau как интегрированной производственной системы. Модель предполагает создание модульной структуры, включающей:

- Цеха полного цикла по производству сварочного оборудования и расходных материалов.
- Участки высокоточной механической обработки, оснащенные токарными станками с ЧПУ, ручными станками и лазерным оборудованием для резки металла.
- Складскую и инженерную инфраструктуру, обеспечивающую эффективную интеграцию производственных и логистических потоков.

Проведенный SWOT-анализ выделил ключевые аспекты проекта:

- Сильные стороны: выгодное территориальное расположение в промышленном регионе, интеграция различных функций в одном комплексе, фокус на локализацию.
- Слабые стороны: высокая капиталоемкость, дефицит квалифицированных кадров, возможные ограничения по номенклатуре на начальном этапе.
- Возможности: глобальный тренд на локализацию, государственная поддержка, потенциал замещения импорта и выхода на рынки Центральной Азии.
- Угрозы: колебания цен на сырье, конкуренция с импортной продукцией, риски сбоя в поставках комплектующих.

Технико-экономическое обоснование проекта ориентировано на повышение уровня локализации, снижение логистических издержек и сокращение сроков поставок за счет внедрения автоматизированных технологий. Практическая значимость заключается в повышении доступности отечественной продукции, укреплении технологической автономии региона и формировании экосистемы квалифицированных поставщиков.

Проведенное исследование подтверждает высокую экономическую и стратегическую целесообразность создания индустриального парка Industrial Park Atyrau. Проект представляет собой эффективный инструмент ответа на ключевые вызовы промышленного сектора Западного Казахстана: импортозависимость, высокие логистические издержки и длительные сроки поставки критически важных материалов и услуг.

Для бизнес-сообщества и индустрии реализация проекта сулит:

1. Снижение операционных рисков: локализация производства повышает устойчивость цепочек поставок и ремонтпригодность оборудования.
2. Сокращение затрат: уменьшаются логистические издержки и косвенные потери от простоев.
3. Повышение гибкости: возможность быстрого реагирования на специфические потребности предприятий региона.
4. Формирование новой компетенции: развитие высокотехнологичного производственного кластера и сопутствующей сервисной экосистемы.

Таким образом, Industrial Park Atyrau является не просто инфраструктурным объектом, а стратегическим проектом, способным catalyzировать технологическую модернизацию региона, повысить его инвестиционную привлекательность и обеспечить

долгосрочную основу для устойчивого промышленного развития. Дальнейшие исследования целесообразно направить на детализацию финансовых моделей и механизмов государственно-частного партнерства для успешной реализации данной инициативы.

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ИННОВАЦИОННАЯ ПЕННАЯ ХИМИЧЕСКАЯ ОЧИСТКА ТЕПЛООБМЕННОГО ОБОРУДОВАНИЯ: ТЕХНИКО-ЭКОНОМИЧЕСКОЕ ОБОСНОВАНИЕ ДЛЯ ПРОМЫШЛЕННОСТИ

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В условиях роста технологической сложности производственных процессов и ужесточения требований к энергоэффективности и экологической безопасности поддержание работоспособности теплообменного оборудования приобретает критическую важность. Загрязнение теплообменных поверхностей приводит к существенному снижению коэффициента теплопередачи, росту энергопотребления, увеличению эксплуатационных затрат и сокращению срока службы оборудования. Особенно остро данная проблема стоит в нефтегазоперерабатывающей и смежных отраслях, где снижение эффективности теплообмена напрямую влияет на производственные показатели и себестоимость продукции. В связи с этим актуальным является поиск и внедрение инновационных, ресурсосберегающих и экологически ориентированных технологий очистки, способных обеспечить устойчивое функционирование производственных систем. Целью представленного исследования стала разработка и технико-экономическое обоснование специализированного оборудования для высокоэффективной пенной химической очистки теплообменников и воздушных охладителей.

Методология и анализ существующих решений

Методологическую основу исследования составили общенаучные и специальные методы, включая анализ и синтез научно-технической документации, системный и структурно-функциональный подход, а также методы сравнительного анализа. В рамках работы был проведен детальный анализ трех доминирующих в промышленности методов очистки теплообменного оборудования.

Механический метод (гидродинамическая очистка, кавитация, пескоструйная обработка) демонстрирует высокую эффективность против застарелых отложений, но характеризуется высокой трудоемкостью, необходимостью полной разборки аппаратов, длительными временными затратами и риском механического повреждения конструктивных элементов, что влечет за собой дополнительные расходы на ремонт и замену частей.

Химический метод, основанный на циркуляции моющих растворов, отличается оперативностью и минимальными трудовыми затратами, поскольку не требует полной разборки. Однако его эффективность резко падает при работе со сложными многослойными загрязнениями. Серьезными ограничениями являются необходимость точного подбора

реагентов под материал поверхностей, а также значительные экологические и финансовые издержки, связанные с утилизацией отработанных химических растворов.

Комбинированный метод, последовательно сочетающий механическое и химическое воздействие, признан наиболее эффективным с точки зрения качества очистки, но при этом наиболее ресурсоемким. Он требует длительных простоев оборудования, высокой квалификации персонала и сопряжен с максимальными затратами.

Ранжирование методов по критериям «удобство» и «эффективность» наглядно показало, что ни один из традиционных подходов не обеспечивает оптимального баланса: химический метод лидирует по удобству, но проигрывает в эффективности; комбинированный – обратная ситуация; механический занимает промежуточное положение по обоим показателям. Данный анализ подтвердил необходимость разработки альтернативной технологии, лишенной указанных системных недостатков.

Разработка и результаты внедрения пенной технологии

В качестве такой альтернативы в исследовании предложена и обоснована технология пенной химической очистки. Ее принцип действия основан на генерации и нанесении на обрабатываемую поверхность пены, содержащей химически активные добавки. Ключевые преимущества данного подхода, выявленные в ходе исследования, включают:

- Длительный контакт с поверхностью: пена обеспечивает пролонгированное воздействие реагентов на загрязнения (от 3 до 30 минут), что значительно повышает эффективность расщепления даже сложных отложений.
- Высокая проникающая способность: технология позволяет обрабатывать труднодоступные участки и поверхности сложной геометрии без разборки оборудования.
- Ресурсная эффективность: расход моющих средств сокращается в 3–5 раз по сравнению с традиционными методами. Для обработки до 120 м² поверхности достаточно 20 литров рабочего раствора. Также существенно снижается потребление воды.
- Экологическая и эксплуатационная безопасность: минимизируется образование токсичных стоков, отсутствует прямой контакт персонала с агрессивными растворами, снижается риск повреждения очищаемых поверхностей.

На основе этих принципов разработано комплексное техническое решение специализированного оборудования. Его ключевые конструктивные и функциональные особенности:

1. Модульная мобильная компоновка, обеспечивающая адаптацию к различным типам теплообменников и воздушных охладителей.
2. Технология «3 в 1», интегрирующая циклы пенной очистки, промывки водой, осушки сухим воздухом и нанесения защитного антикоррозионного покрытия.
3. Интеллектуальная система управления, включающая цифровое дозирование реагентов и возможность дистанционного контроля процесса.
4. Работа в замкнутом цикле с повторным использованием раствора, что дополнительно снижает расходы и экологическую нагрузку.

Технико-экономическое обоснование проекта указывает на следующие прямые выгоды от внедрения:

- Сокращение времени простоя технологического оборудования в процессе обслуживания.
- Снижение затрат на очистку за счет уменьшения расхода химических реагентов и воды.

- Повышение качества очистки и, как следствие, восстановление номинального коэффициента теплопередачи, что ведет к снижению энергопотребления.
- Экономическая целесообразность как при использовании в рамках собственного производства предприятия, так и при оказании сервисных услуг сторонним компаниям.

Проведенное исследование убедительно демонстрирует, что инновационная технология пенной химической очистки в сочетании со специализированным интеллектуальным оборудованием представляет собой стратегически значимое решение для современной промышленности. В отличие от традиционных методов, она предлагает оптимальный синергетический эффект, объединяя высокую технологическую эффективность, экономическую целесообразность и соответствие строгим экологическим стандартам.

Практическая значимость и бизнес-привлекательность разработки заключаются в ее способности напрямую влиять на ключевые операционные и финансовые показатели промышленных предприятий. Внедрение решения позволяет:

1. Повысить операционную эффективность за счет сокращения плановых и внеплановых простоев критически важного теплообменного оборудования.
2. Снизить совокупную стоимость владения путем уменьшения затрат на реагенты, воду, энергоносители и утилизацию отходов.
3. Минимизировать операционные риски, связанные с повреждением оборудования при чистке и нарушением экологического законодательства.
4. Создать новую сервисную бизнес-модель для специализированных компаний, оказывающих услуги промышленной очистки с использованием передовых технологий.

Потенциал коммерциализации технологии высок и подтверждается четко определенными сферами применения: нефтегазовый сектор, химическая промышленность, агропромышленный комплекс и ЖКХ. Таким образом, разработанное решение не только отвечает на актуальные технологические вызовы, но и обладает выраженной коммерческой ценностью, открывая пути к оптимизации издержек и повышению конкурентоспособности предприятий в условиях растущего давления на эффективность и устойчивость.

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3D-СКАНИРОВАНИЕ И РЕВЕРС-ИНЖИНИРИНГ КАК КЛЮЧЕВЫЕ ФАКТОРЫ ТРАНСФОРМАЦИИ ПРОМЫШЛЕННОГО РЕМОНТНОГО СЕРВИСА В КАЗАХСТАНЕ

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Предприятия нефтегазовой, химической и смежных отраслей Казахстана сталкиваются с существенными экономическими и технологическими вызовами, связанными с обеспечением непрерывности производства. Высокие затраты и длительные простои оборудования, обусловленные недостаточной локальной ремонтной базой, зависимостью от импортных запасных частей и ограниченными возможностями традиционных сервисов, напрямую снижают производственную эффективность и конкурентоспособность [3]. В условиях глобальных трансформаций цепочек поставок и усиления политики импортозамещения, развитие отечественного высокотехнологичного ремонтного сервиса переходит из разряда опциональных улучшений в категорию стратегических задач экономической и технологической безопасности [1, 8, 13].

Актуальность данного исследования обусловлена необходимостью перехода от эмпирических методов ремонта к цифровым процессным моделям, основанным на точных данных. Целью работы является разработка и научное обоснование современной системы ремонтного сервиса (Repair Service), обеспечивающей внедрение технологий 3D-сканирования, реверс-инжиниринга и индивидуальных решений по восстановлению и модернизации оборудования для ключевых отраслей промышленности Казахстана.

Методология и подходы

Методологическую основу исследования составил комплекс аналитических инструментов, адаптированных для оценки промышленного ремонтного комплекса. Для анализа внешней и внутренней среды отрасли был применен SWOT-анализ. Ландшафтный анализ позволил оценить состояние логистики и инфраструктуры ремонта. Ключевым элементом стал технологический аудит производственных и диагностических мощностей с фокусом на оценку потенциала внедрения высокоточных цифровых технологий, включая 3D-сканирование и CAD/CAM-интеграцию.

Такой многоуровневый подход позволил не только выявить системные проблемы отрасли (низкий уровень автоматизации, дефицит инвестиций, отсутствие цифровых моделей оборудования), но и оценить практическую применимость конкретных технологических решений в реальных производственных условиях предприятий Казахстана.

Анализ технологического решения и результаты

Новизна предлагаемой системы заключается в интеграции трех ключевых компонентов: промышленного 3D-сканирования, цифровой библиотеки деталей и реверс-инжиниринга. Данный симбиоз технологий формирует замкнутый цикл «диагностика – моделирование – производство».

1. 3D-сканирование и диагностика: Обеспечивает создание высокоточной цифровой копии (облака точек) изношенной или поврежденной детали с точностью до 0,01–0,02 мм.
2. Реверс-инжиниринг (обратное проектирование): На основе данных сканирования в инженерно-проектном модуле (CAD/CAM/CAE) воссоздается или оптимизируется цифровая 3D-модель детали, даже при отсутствии оригинальной документации.
3. Цифровая библиотека и производство: Созданные и оптимизированные модели накапливаются в цифровой библиотеке, что ускоряет повторные заказы и позволяет организовать локальное производство деталей на станках с ЧПУ (CAM).

Проведенный сравнительный анализ оборудования (Таблица 1 отчета) показал, что для задач промышленного ремонта наиболее эффективны лазерные 3D-сканеры (например, Shining 3D FreeScan UE Pro), сочетающие высокую точность, портативность и устойчивость к условиям цеха. Для сверхточных лабораторных задач целесообразно использование сканеров на структурированном свете (RangeVision PRO II).

Разработанная концепция системы промышленного ремонтного сервиса, основанной на цифровых технологиях, представляет собой не просто техническое решение, а новую бизнес-модель для рынка сервисных услуг. Ее внедрение обеспечивает достижение измеримых экономических результатов, подтверждающих высокую инвестиционную привлекательность:

- Снижение операционных затрат: Сокращение затрат на ремонт и обслуживание на 30–40% за счет локализации производства запчастей и оптимизации процессов.
- Увеличение производительности: Сокращение сроков ремонта и простоев оборудования на 25–35% за счет ускорения процессов диагностики и изготовления деталей.
- Повышение технологической независимости: Снижение зависимости от импорта запасных частей до 50%, что укрепляет устойчивость предприятий к внешним рискам.
- Увеличение стоимости активов: Продление срока службы оборудования и возможность его модернизации повышают отдачу от капитальных вложений.
- Формирование новых компетенций: Создание цифровых библиотек деталей превращает ремонт из затратной операции в управляемый актив, открывая возможности для прогнозного обслуживания.

Практическая значимость для бизнеса заключается в создании сервисных производств с высокой добавленной стоимостью, ориентированных на нефтегазовый сектор, нефтехимию и машиностроение. Система позволяет не только восстанавливать, но и оптимизировать детали, повышая их ресурс, что создает дополнительную ценность для клиента. Потенциал коммерциализации подтверждается четко определенной областью применения, рассчитанным экономическим эффектом и модульной архитектурой решения, позволяющей масштабировать услуги. Таким образом, интеграция 3D-сканирования и реверс-инжиниринга является стратегическим направлением для модернизации промышленности Казахстана, напрямую влияющим на рост ее конкурентоспособности и технологического суверенитета.

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Legal Sciences

The Legal, Constitutional, and Ethical Aspects of Medical Assistance in Dying in the State of New York

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Abstract

This paper will examine the current constitutional debate in the State of New York regarding Medical Aid in Dying (MAID), a practice distinct from but related to palliative care in its focus on end-of-life autonomy and patient dignity. In June 2025, the New York State Legislature approved the Medical Aid in Dying Act, signifying the New York's first comprehensive legislative recognition of the right of terminally ill, mentally competent adults to request life-ending medication under defined medical safeguards. The bill, now awaiting the governor's signature, places New York at the center of a national dialogue over whether the Fourteenth Amendment's guarantee of equal protection and substantive due process encompass the right to a medically assisted death. Building on the precedents of *Vacco v. Quill* (521 U.S. 793 (1997)) and *Washington v. Glucksberg* (521 U.S. 702 (1997)), this paper argues that New York's failure to implement the Act after legislative passage would not merely represent a policy hesitation, but a potential constitutional breach that undermines evolving interpretations of personal liberty, bodily integrity, and state responsibility in modern constitutional law.

Key words: *Medical Aid in Dying (MAID); assisted suicide; patient autonomy; palliative care;*

Introduction

In constitutional law, medical ethics, and public policy, the question of whether terminally ill individuals should be able to seek medical assistance to hasten their death was one of the most controversial issues in the United States. While several states, such as Oregon, Washington, and more recently New Jersey, Maine and California have enacted legislation allowing medical assistance in dying under thorough procedural safeguards, the State of New York has repeatedly declined to do so despite legislative efforts and wide public debate.

However, in June 2025, the New York State Legislature approved the Medical Aid in Dying Act¹, marking the first time the bill has passed both chambers (Grace Ashford, N.Y. Times, June 9, 2025), and it is still awaiting NY Governor Kathy Hochul's endorsement, which is a pivotal moment that could position New York alongside eleven other U.S. jurisdictions that have already authorized MAID. Should the governor Hochul sign it, and does she now have a constitutional *duty* to do so?

The answer to this question depends on whether New York's continued hesitation can still be justified under the constitutional standards articulated by the United States Supreme Court in *Vacco v. Quill* and *Washington v. Glucksberg*, or whether evolving ethical norms, empirical

¹ Grace Ashford, New York Moves to Allow Terminally Ill People to Die on Their Own Terms, N.Y. Times (June 9, 2025).

evidence from other states, and shifting interpretations of the Fourteenth Amendment's guarantees of equal protection and substantive due process impose a stronger obligation on the state to recognize medical aid in dying as a protected liberty and public interest. This also required not only a legal analysis of the past precedent, but also a critical evaluation of whether the assumptions underlying those decisions, especially regarding the state's interest in preserving life and preventing abuse, remain persuasive given almost three decades of data from states that have already legalized MAID.

In *Vacco v. Quill* (521 U.S. 793 (1997))² and *Washington v. Glucksberg* (521 U.S. 702 (1997))³, the United States Supreme Court upheld state bans on assisted suicide, emphasizing the legitimacy of state interests in preserving life, preventing abuse, and protecting vulnerable individuals. Yet, these rulings also left open the possibility that future developments, both legal and societal, could lead to different constitutional outcomes. As other states have moved forward with carefully regulated assisted dying processes, New York's continued prohibition now raises pressing questions under the Fourteenth Amendment's⁴ Equal Protection and Due Process Clauses. The Fourteenth Amendment states:

*"No state shall make or enforce any law which shall abridge the privileges or immunities of citizens of the United States; nor shall any state deprive any person of life, liberty, or property, without due process of law; nor deny to any person within its jurisdiction the equal protection of the laws"*⁵

Whether the state's position in light of modern medical realities and growing recognition of patient autonomy requires further analysis is the key question being examined in this paper.

This paper critically examines the evolving legal, constitutional, and ethical milieus of MAID in New York in its five-part analysis. In Part I, the paper discusses the development of MAID legislation across the United States and explains how federalism has produced a state-by-state "laboratory of democracy". Part II examines why New York resisted legalization for nearly a decade and identifies the political and institutional shifts that led to the 2025 legislative breakthrough. Part III assesses whether New York's continued hesitation has become constitutionally vulnerable under evolving interpretations of the Equal Protection and Due Process Clauses. Part IV discovers the ethical conflict between autonomy-centered and protection-centered models of the state responsibility at the end of life. Part V examines empirical data from jurisdictions where MAID has been legalized, demonstrating that the practice has operated safely, contrary to early speculative fears.

Part I: Development of Assisted Dying Legislation in the United States

The legal treatment of medical assistance in dying in the United States has evolved unevenly over the past three decades, as individual states have adopted sharply divergent approaches to end-of-life decision making. Modern legislative history begins with Oregon's first-of-a-kind Death with Dignity Act of 1994⁶, the first law in the United States to legalize physician-assisted dying for terminally ill, mentally competent adults with a prognosis of six months or less to live (Rev. Stat. §127.800-897 (1994)). After surviving a referendum challenge and going into

² *Vacco v. Quill*, 521 U.S. 793 (1997)

³ *Washington v. Glucksberg*, 521 U.S. 702 (1997).

⁴ U.S. Const. amend. XIV.

⁵ *Id.*

⁶ Or. Rev. Stat. §§ 127.800–.897 (1994).

effect in 1997, Oregon's model became the framework upon which most subsequent state laws have been proposed, incorporating strict safeguards such as multiple physician certifications, waiting periods, and voluntary written requests by the patient.

Following Oregon, Washington State legalized assisted dying in 2008, also through voter referendum, explicitly modeling its law on Oregon's. In the years that followed, the movement expanded gradually: Vermont passed its Act 39 through legislation in 2013, becoming the first state to legalize Medical Aid in Dying (MAID)⁷ through legislative rather than voter action. California enacted the End of Life Option Act in 2015⁸, Colorado followed by referendum in 2016⁹, and the District of Columbia passed a similar legislation in 2017¹⁰. More recently, states such as Hawaii (2019)¹¹, Maine (2019)¹², and New Jersey (2019)¹³ have enacted MAID statutes, as well as New Mexico (2021)¹⁴. As for today, at least eleven U.S. jurisdictions including Oregon, Washington, California, Colorado, Vermont, New Jersey, Maine, Hawaii, New Mexico, the District of Columbia and most recently, Montana¹⁵, allow some form of medical aid in dying.

If I step away from the topic of assisted dying for a moment, and think of another controversial topic, marijuana, for instance. As with the legalization of recreational marijuana, states, such as Colorado and Washington, were the first to adopt legislation despite federal prohibition under the Controlled Substances Act of 1970 (21 U.S.C. §801)¹⁶. In both scenarios, marijuana and MAID have followed a federalist model, permitting individual states to function as "laboratories of democracy" and to enact policies that reflect the moral, cultural and political preferences of their own populations, even in the absence of national consensus of federal uniformity. This illustration displays that the states enjoy their autonomy over health, safety, and moral regulation under the American constitutional structure and they can diverge drastically from one another so long as their actions do not violate federal constitutional limits.

Now, in contrary, many other states have explicitly criminalized assisted suicide, reinforcing their interest in preserving life and preventing abuse or coercion¹⁷. State, such as, Texas, Florida and North Carolina still treat physician-assisted suicide as a criminal offense, and numerous legislative attempts to legalize MAID have failed, mostly due to opposition from religious institutions, disability rights advocates, and some sectors of the medical community. Therefore, rather than moving toward national uniformity, the United States has developed what

⁷ *Patient Choice and Control at End of Life Act*, 2013 Vt. Acts & Resolves 39 (codified at Vt. Stat. Ann. tit. 18, §§ 5281–5293).

⁸ *End of Life Option Act*, 2015 Cal. Stat. ch. 1 (2d Extraordinary Sess.) (codified at Cal. Health & Safety Code §§ 443–443.22).

⁹ *End-of-Life Options Act*, Colo. Rev. Stat. §§ 25-48-101 to -123 (2016).

¹⁰ *Death with Dignity Act of 2016*, D.C. Law 21-182, codified at D.C. Code §§ 7-661.01–.17 (2017).

¹¹ *Our Care, Our Choice Act*, 2018 Haw. Sess. Laws Act 2 (codified at Haw. Rev. Stat. §§ 327L-1 to -25).

¹² *Death with Dignity Act*, 2019 Me. Laws ch. 271 (codified at Me. Stat. tit. 22, §§ 2140–2140A).

¹³ *Medical Aid in Dying for the Terminally Ill Act*, 2019 N.J. Laws 59 (codified at N.J. Stat. Ann. §§ 26:16-1 to -20).

¹⁴ *Elizabeth Whitefield End-of-Life Options Act*, 2021 N.M. Laws ch. 54 (codified at N.M. Stat. Ann. §§ 24-7C-1 to -8).

¹⁵ *Baxter v. State*, 224 P.3d 1211 (Mont. 2009) (holding that physician-assisted aid in dying is not prohibited under Montana law and that physicians may raise patient consent as a defense to homicide charges).

¹⁶ Controlled Substances Act, 21 U.S.C. §§ 801–971 (2018).

¹⁷ Am. Bar Ass'n Comm'n on Law & Aging, *Legislative Fact Sheet: Medical Aid in Dying* 1–2 (2023).

scholars frequently refer to as a state-by-state “laboratory of democracy”, with legality of assisted dying determined almost entirely by local political will and moral culture.

Part II: Why Did it Take New York a Decade to Finally Move, and What Changed in 2025?

For nearly a decade, New York remained one of the most actively debated yet legally stagnant states on the question of MAID. Beginning in 2015, lawmakers repeatedly introduced variations of the MAID, most recently Assembly Bill A995 and Senate Bill S2445 (2023-2024 session),¹⁸ modeled closely on Oregon’s Death with Dignity framework. Despite New York’s reputation as a socially progressive jurisdiction, every version of the bill failed to advance beyond committee, not because the state constitution prohibited MAID, but because of deep differences in moral viewpoints, institutional caution, and powerful coalition resistance.

Legally, New York’s state constitution does not explicitly bar assisted dying. In comparison to other states that have constitutional provisions defining life from conception or elevating religiously rooted doctrines, New York’s Constitution leaves end-of-life regulation to the state legislature through its broad “police power” over health, safety and welfare when stating:

“The protection and promotion of the health of the inhabitants of the state are matters of public concern and provision therefor shall be made by the State” (N.Y. Const. Art XVII §3).¹⁹

Courts have historically upheld state laws on abortion, public health and bodily autonomy using this flexible standard, meaning MAID was always legally permissible to authorize if the legislature chose to do so. In other words, New York’s barrier was never legal, it was political and ethical.

For almost a decade, the opposition was anchored by the New York State Catholic Conference, disability rights coalitions such as *Not Dead Yet*²⁰, and legislators who feared what they called a slippery slope towards devaluing elderly, disabled, or low-income lives. In the same vein, support grew more slowly on the institutional side: early backing was limited to civil liberties organizations, but over time the New York State Bar Association²¹, and the Medical Society of the State of New York.²²

An advancement for MAID takes place in 2025 for the State of New York, after years of legislative gridlock, both chambers of the New York State Legislature passed MAID for the first time in history. The Bill’s language was deliberately narrow, applying only to mentally competent adults with a terminal illness and a prognosis of six months or less, and it emphasizes autonomy, dignity, and physical oversight rather than any broader “right to die”. This breakthrough was not a spontaneous moral shift, it was the result of accumulated legal legitimacy from other states, institutional normalization, and growing equal protection arguments from advocates who

¹⁸ N.Y. Assembly Bill A995-A (2023–2024 Reg. Sess.), Summary, N.Y. Senate, available at: <https://legislation.nysenate.gov/pdf/bills/2023/A995A>.

¹⁹ N.Y. Const. art. XVII, § 3.

²⁰ Not Dead Yet, *Homepage*, <https://notdeadyet.org/> (Oct. 24, 2025).

²¹ N.Y. State Bar Ass’n, Support for the New York Medical Aid in Dying Bill (June 18, 2025).

²² Medical Society of the State of New York, “MSSNY Announces Support of Medical Aid in Dying Act,” (MSSNY, Apr. 15, 2024).

demanded to know why New York should have less end-of-life autonomy than residents of Oregon, California, Washington, New Jersey or even Washington D.C. With this advancement, the legal question has shifted from legislative discretion to constitutional responsibility as the bill awaits for the Governor's signature.

Part III: Does New York Now Risk Violating the Constitution? Equal Protection and Substantive Due Process After *Vacco* and *Glucksberg*

When the U.S. Supreme Court decided *Vacco v. Quill* and *Washington v. Glucksberg* in 1997, it upheld New York's and Washington State's bans on physician-assisted "suicide", but critically, it did not hold that states are constitutionally prohibited from allowing it. Instead, the Court concluded only that the Constitution does not require states to legalize MAID. Justice Rehnquist emphasized in *Glucksberg* that the Court was not "foreclosing" future evolution should "changing circumstances" or "further developments" alter the constitutional landscape. That precise possibility is now at the core of New York's current dilemma.

The central protection rationale in *Vacco v. Quill* was that New York's then-existing law treated all terminally ill patients the same, meaning they could refuse life-sustaining treatment (which is legal), but none could actively receive physician assistance to hasten death. At that time, there was no evidence that this distinction resulted in unequal or discriminatory treatment. Today, however, the landscape has materially changed. Eleven states and D.C. now authorize MAID, while New York patients with identical terminal prognoses must either suffer at length or travel, if they have means to exercise the same autonomy. The emerging constitutional question is whether New York is now arbitrarily denying bodily autonomy to one class of dying patients while that same autonomy is recognized as lawful, safe, and regulated elsewhere in the United States. That is no longer a hypothetical disparity, it is a real widening one.

In *Glucksberg*, the Court rejected the claim that physician-assisted dying was a "fundamental right" narrowing and historically defined. However, it did so while acknowledging that the right to refuse medical treatment grounded in bodily integrity and autonomy is constitutionally protected.²³ The question today is whether MAID has evolved, though empirical evidence and national adoption, into a modern extension of that same autonomy principle, in other words, it is constitutionally compliant for New York to protect a competent patient's right to refuse a ventilator or dialysis, even if death is certain, yet deny that same patient the right to choose a medically peaceful death rather than a prolonged, agonizing one. That asymmetry, some scholars argue, is increasingly untenable under substantive due process logic.

The factual basis on which *Vacco* and *Glucksberg* were decided no longer exists in 2025. Then, MAID was largely theoretical. No American jurisdiction had decades of peer-reviewed evidence. Today, Oregon, Washington, and California have nearly thirty combined years of data demonstrating strict safeguards, low utilization, no evidence of systematic abuse, and overwhelming patient-driven choice. The burden has quietly shifted: New York can no longer rest on speculative fears that legalizing MAID would lead to involuntary euthanasia or discrimination.

Based on this narrative, the constitutional posture has inverted. In 1997, the Court asked whether states must allow MAID. With MAID now passed by the Legislature and awaiting the governor's decision, New York is no longer facing abstract moral debate, it is facing a moment of potential constitutional reckoning.

²³ Id. at 720 (citing *Cruzan v. Dir., Mo. Dep't of Health*, 497 U.S. 261, 278 (1990)).

Part IV: Autonomy and Protection of the Vulnerable

The ethical debate over MAID reflects a deeper philosophical divide between two conceptions of the state's role in end-of-life decision-making. Supporters rely on liberal individual autonomy framework based on the belief that a competent person retains the ultimate authority over their own body, including the manner and timing of death, so long as that decision is made voluntarily and with full medical oversight²⁴. Opponents, on the contrary, invoke a communitarian and protective ethical model, which holds that the state bears an affirmative duty to err on the side of preserving life, particularly where structural inequities or impaired consent may exist.²⁵ The future of MAID policy in New York therefore depends not only on medical or legal developments but on which philosophical understanding of state responsibility: autonomy-centered or protection-centered, the law chooses to prioritize.

This ethical debate surrounding MAID centers on how the law should balance individual autonomy, particularly the right of a terminally ill patient to make deeply personal end-of-life decisions, with the state's responsibility to protect individuals who may be vulnerable to coercion, discrimination, or inequity. These competing principles both carry substantial legal and moral weight, and neither can be invalidated without further critical evaluation.

Proponents of MAID, including Compassion & Choices, the New York State Bar Association, and the Medical Society of the State of New York, highlight that competent adults already possess the well-established right to refuse life-sustaining medical treatment, even when doing so will result in certain death, a right recognized by the Supreme Court in cases such as *Cruzan v. Dir., Mo. Dep't of health*, 497 U.S. 261, 278 (1990)²⁶. From this perspective, MAID is not a departure from existing legal doctrine, but a clarification of it, allowing a terminally ill patient to avoid prolonged suffering in a medically supervised and voluntary manner. Advocates argue that forcing such individuals to continue a process of physical deterioration against their will may undermine, rather than preserve, the dignity and autonomy that the law seeks to protect.

Opponents of MAID, such as the New York State Catholic Conference and the disability rights nonprofit Not Dead Yet, on the other hand, cite ethical concerns grounded in the Americans with Disability Act (ADA)²⁷ posit MAID not only as an ethical question about individual choice but also as a structural question about health care fairness and the risk of indirect coercion. Disability rights advocates and certain medical ethicists have argued that socio-economic pressures, uneven access to palliative care, and insurance-driven cost incentives could influence end-of-life decisions in ways that are not entirely voluntary. According to the opponents of MAID, legalizing MAID without sufficient check controls can risk normalizing death as a cost-efficient alternative for those who are elderly, disabled, or economically marginalized.

²⁴ See, e.g., Ronald Dworkin, *Life's Dominion: An Argument About Abortion, Euthanasia, and Individual Freedom* (1993); *Cruzan v. Dir., Mo. Dep't of Health*, 497 U.S. 261, 278 (1990).

²⁵ See, Not Dead Yet, *Position Statement on Assisted Suicide*, <https://notdeadyet.org/> (last visited Oct. 24, 2025); N.Y. State Catholic Conference, *Testimony in Opposition to Medical Aid in Dying Legislation* (2024).

²⁶ *Cruzan v. Dir., Mo. Dep't of Health*, 497 U.S. 261, 278 (1990).

²⁷ Americans with Disability Act of 1990, 42 U.S.C. §§ 12101-12213 (2018).

Part V: Empirical Data and Patient Demographics from the States That Have Legalized MAID, What Can We Learn From Them?

Empirical evidence from the states that have legalized MAID demonstrates that the practice remains limited in scope and carefully regulated. In Oregon, which has published annual reports since 1998, MAID accounts for fewer than 0.7% of all deaths each year.²⁸ Comparable data from Washington and California show similar usage rates²⁹. Most participants are patients with terminal cancer, overwhelmingly insured, and already enrolled in hospice care at the time of their request.³⁰ These findings contradict early fears that legalization of MAID would contribute to widespread impulsive use of the procedure. The demographics instead suggest that MAID primarily educated, middle-class patients making informed choices at the end of life.

In terms of the safeguards and regulatory compliance, all MAID statutes in the United States share a core regulatory model based on Oregon's Death with Dignity Act (Or. Rev. Stat. 127.800-.897). Each requires: 1) two independent physicians to confirm a terminal diagnosis of six months or less; 2) a determination of the patient's mental competence and consent, 3) two oral requests and one written request witnessed by disinterested party, and 4) also report all cases to the state health authority, which audits compliance annually³¹. Across more than two decades of compilation of data, Oregon and Washington have found no verified cases of coercion or abuse and no disciplinary findings for physicians acting within statutory parameters³². California's Department of Public Health has reported similar findings since the End of Life Option Act took effect in 2016.³³

The accumulated empirical record undermines the justifications New York relied on when *Vacco v. Quill* was decided in 1997. At that time, the Supreme Court deferred to speculative state interests in preventing abuse and preserving life. Today, more than two decades of data indicate that those interests can be protected through robust statutory safeguards. Should Governor Hochul sign the MAID, New York would enter a policy environment informed by empirical validation.

Where the Law Must Go Now?

As I offer my final remarks to this piece, it is important to think that nearly three decades after *Vacco v. Quill* and *Washington v. Glucksberg*, the legal and factual landscape surrounding MAID has *fundamentally* shifted. It was once a speculative, untested proposition, but now it is an empirically grounded, carefully regulated medical practice in 11 states. In 1997, the constitutional question facing New York was what the state could rationally prohibit; in 2025, it is whether it can do so without violating equality, autonomy, and rationality.

As seen in this analysis, the statutory framework acceptable in other states has operated with robust safeguards, voluntary participation, and no measurable threat to vulnerable populations. Ethical concerns remain consequential but no longer hypothetical, they are now

²⁸ Oregon Health Auth., *Oregon Death with Dignity Act: 2024 Data Summary 1* (2025) (covering data 1998-2023).

²⁹ Wash. State Dep't of Health, *Death with Dignity Act 2024 2* (2024).

³⁰ Id.; Cal. Dep't of Pub. Health, *California End of Life Opinion Act 2024 Data Report 3* (2024)

³¹ See, e.g., Or. Rev. Stat. §§ 127.805(1), 127.815(1) (2024); Wash. Rev. Code §§ 70.245.020-.040 (2024); Cal. Health & Safety Code §§ 443/1-22 (2024).

³² Id.; Wash. State Dep't of Health, *supra* note 2, at 6.

³³ Cal. Dep't of Pub. Health, *supra* note 3, at 5.

informed by observable data rather than prediction. New York can no longer rely on speculative fears that instigated resistance when confronted with concrete evidence that MAID functions as a narrow, patient-centered medical option rather than a destabilizing societal threat.

Thus, the constitutional posture has inverted: what was once a question of legislative permission is rapidly becoming a question of constitutional obligation. If Governor Hochul signs the MAID into law, New York will align itself with an emerging national standard that modern jurisprudence appears increasingly willing to recognize. If she declines, the state risks confronting a constitutional challenge, not for acting prematurely, but for failing to act in the face of evolved legal doctrine, compelling ethical justification, and overwhelming empirical validation.

“Left on Read”: Cyber Incivility and Emotional Exhaustion in Hybrid IT Workplaces in Kazakhstan

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Abstract: Workplace incivility low-intensity, ambiguous disrespect has become increasingly common in hybrid and digital work settings, yet its manifestation in post-Soviet, multilingual, high power-distance contexts such as Kazakhstan remains underexplored. This study examines how employees in Almaty’s IT and digital organizations experience offline and cyber incivility, how these behaviors relate to emotional exhaustion and work attitudes, and which relational and cultural factors shape their impact. Using a qualitative interpretivist approach, semi-structured interviews were conducted with fifteen IT professionals working in hybrid formats. Thematic analysis showed that incivility is often subtle, stress-driven, and embedded in everyday digital communication. Cyber incivility such as selective ignoring, abrupt tone, unclear task assignments, and minimal responses was perceived as especially harmful due to heightened ambiguity and lack of contextual cues. In line with Conservation of Resources (COR) theory, repeated exposure to incivility contributed to emotional depletion, reduced motivation, and withdrawal from collaboration. Supervisor trust and forgiving team climates emerged as key buffers, while hierarchical norms and multilingual tone variation intensified sensitivity to disrespectful or unclear communication. The study extends organizational behavior research by highlighting digital ambiguity as a distinct mechanism of resource loss and offers practical recommendations for improving respectful communication in hybrid workplaces.

Keywords: *Workplace incivility; Cyber incivility; Hybrid work; Conservation of Resources (COR) theory; Leader–Member Exchange (LMX); Organizational justice; Multilingual communication; Power distance; Emotional exhaustion; IT sector; Kazakhstan; Qualitative research; Thematic analysis.*

Introduction

Workplace incivility (WI) refers to low-intensity, norm-violating behaviors with ambiguous intent eyerolling, interruptions, dismissive tone, public silence in group chats, or being “left on read” that breach expectations of courtesy and respect (Cortina et al., 2001; Pearson & Porath, 2005). While individually minor, their cumulative effect erodes social cohesion, psychological safety, and trust within organizations. Prior research consistently links WI to stress, emotional exhaustion, reduced job satisfaction and engagement, absenteeism, and turnover intentions (Namin et al., 2021; Hasson & Villaume, 2024). In digitized, hybrid work environments, passive cyber incivility, delayed responses, selective acknowledgment, exclusion from decision threads further magnifies ambiguity and undermines intrinsic motivation (Lu et al., 2025; Ju & Pak, 2025).

As a result, the managerial challenge has shifted from merely recognizing incivility to understanding its relational mechanisms, contextual triggers, and systemic drivers.

From an Organizational Behavior (OB) standpoint, incivility is conceptualized not as isolated interpersonal friction but as a relational, systemic process embedded in social exchange patterns and organizational norms. Social Exchange Theory frames incivility as a disruption of reciprocity: violations of interpersonal respect provoke withdrawal or retaliation, producing “incivility spirals.” Organizational Justice research highlights interactional unfairness, disrespectful or dismissive communication as a key factor that diminishes trust, voice, and inclusion. Leader–Member Exchange (LMX) theory shows that low-quality supervisor–employee relationships expose individuals to more slighting behaviors and fewer opportunities for repair, whereas high-LMX dyads buffer harm through support and dialogue. Psychological contract and Person Organization fit perspectives explain how recurring micro-violations signal that disrespect is tolerated, producing cynicism and identity threat. Organizational climate constructs, such as diversity climate and forgiveness climate, help determine whether incivility is contained or amplified. Under macro-level disruptions, such as pandemics or political instability, even positive climates may offer “unequal protection,” exposing vulnerable groups (Shen et al., 2023). Together, these frameworks connect individual perception, relational asymmetries, and structural norms, indicating that effective interventions must extend beyond etiquette training toward redesigning climate, communication structures, and relational trust.

Conservation of Resources (COR) theory provides a dominant mechanism explaining the effects of incivility. COR posits that individuals strive to acquire and protect finite resources (energy, status, belonging). Repeated exposure to ambiguous slights drains these resources, producing emotional exhaustion, defensive withdrawal, and reduced engagement. Empirical serial mediation models show that incivility erodes perceived insider status, which subsequently diminishes affective commitment and identification and ultimately weakens engagement (Guo et al., 2020). Moderated-mediation evidence highlights buffers such as supervisor trust, forgiveness climate, conflict management skills, and psychological capital (Khan et al., 2021; Saleem et al., 2022; Butt & Yazdani, 2021). Longitudinal studies also confirm escalation patterns: unresolved low-intensity incivility may develop into bullying (Holm et al., 2015; 2022). While cross-sectional surveys dominate the field, recent meta-analyses and multi-wave designs improve causal inference and reduce common-method bias (Reich & Hershcovis, 2014; Namin et al., 2021).

1.1 Background to the Study

The present study examines incivility within the IT and digital services sector in Almaty, Kazakhstan, a rapidly expanding industry shaped by hybrid work models, international teams, and high reliance on digital communication platforms. Typical IT organizations in this context are medium-sized product or outsourcing companies with cross-functional teams (engineering, product management, QA, DevOps) and matrix reporting structures. Leadership is often distributed across team leads and project managers, with decision-making influenced by both global agile practices and local hierarchical expectations.

Organizational culture in Almaty’s IT sector blends global IT norms, informality, speed, horizontal collaboration with Kazakhstan’s cultural characteristics, such as respect for authority, age-related hierarchy, collectivist conflict avoidance, and multilingual communication (Kazakh, Russian, English). These factors shape how tone, silence, directness, and feedback are interpreted. Socio-cultural dynamics, generational diversity, and linguistic variation frequently create ambiguity in digital messages, making cyber incivility more salient.

At the country level, Kazakhstan’s transitioning economy, strong state involvement in digitalization, and post-Soviet managerial legacies contribute to mixed expectations regarding communication and leadership. While agile and Westernized communication styles are gaining

traction, many employees still interpret blunt criticism or public silence through hierarchical or culturally sensitive lenses. This produces a unique environment where hybrid work, technological overload, and cultural norms intersect, making Almaty an ideal site for examining workplace and cyber incivility.

1.2 Research Problem

Despite extensive global research on workplace incivility (WI), significant gaps remain regarding how incivility is enacted, perceived, and interpreted in post-Soviet, multilingual, and high power-distance environments such as Kazakhstan. Existing scholarships are predominantly based on Western organizational contexts, where communication norms emphasize directness, low hierarchy, and explicit feedback. As a result, many foundational assumptions such as what constitutes a “rude” tone, whether silence signals disrespect, or how employees should respond to ambiguous digital behaviors do not easily transfer to Central Asian work environments.

In Kazakhstan, communication norms are shaped by a combination of post-Soviet managerial traditions, respect for age and authority, collectivist values, and multilingual interaction (Kazakh, Russian, English). These cultural characteristics influence how employees interpret tone, hierarchy, and interpersonal boundaries. For example, delayed responses in group chats, abrupt instructions, or selective message acknowledgment may be seen as normal efficiency behavior or as subtle disrespect depending on language, relationship quality, or power distance. Such ambiguity is amplified in hybrid and remote IT teams, where 70–90% of communication occurs through digital platforms rather than face-to-face interactions.

Western “civility training” frameworks, often imported by local companies, assume low context cultures and may overlook deeper relational mechanisms such as LMX asymmetry, resource depletion, and organizational communication climate. Consequently, they fail to address why incivility persists and how employees in Kazakhstan cope with subtle disrespect or ambiguous digital signals.

Thus, the core research problem is the absence of contextually grounded, empirical evidence explaining:

- how workplace and cyber incivility are experienced in Kazakhstan’s IT sector,
- why these behaviors emerge within hybrid and multilingual communication conditions, and
- what factors such as a forgiving climate, trust in leadership, or cultural norms buffer or intensify their negative consequences.

This gap limits both theoretical applicability and the effectiveness of organizational interventions designed to support employee well-being and collaboration.

1.3 Significance of the Study

This study holds strong relevance for both theoretical advancement and organizational practice.

Theoretical Significance

First, the research extends the global WI and cyber incivility literature into a non-Western, culturally complex context. Kazakhstan provides a distinctive combination of high power distance, collectivist tendencies, multilingual communication, and hybrid IT work arrangements conditions that remain underrepresented in academic studies. By examining how resource erosion (as described by COR theory), LMX asymmetries, and justice perceptions unfold in this environment, the study enriches existing OB frameworks with culturally sensitive insights.

Second, the study contributes to the emerging discourse on cyber incivility, an increasingly relevant phenomenon as digital communication becomes the primary channel in IT sectors. It highlights how digital ambiguity interacts with cultural expectations, linguistic interpretation, and

hierarchical norms, offering a more nuanced understanding of cyber behavior than the current Western-centric models.

Practical Significance

For organizations, the study provides actionable, contextually tailored guidance for improving workplace climate, communication processes, and leadership practices. Specifically, it helps companies:

- identify how “small” acts of incivility escalate into emotional exhaustion and turnover intentions,
- understand cultural triggers behind tone misinterpretation and digital silence,
- strengthen leader–member relationships through transparent communication and timely conflict intervention,
- design communication norms that reflect hybrid work realities in Kazakhstan, and
- implement forgiveness climate practices that reduce stress and facilitate recovery after interpersonal friction.

Given Kazakhstan’s rapid digitalization and the central role of IT talent in national economic development, promoting psychologically healthy and respectful workplaces has growing strategic significance. This study contributes to that goal by informing policy, managerial training, and organizational development initiatives aimed at increasing employee well-being, retention, and team effectiveness.

1.4 Research Questions

Building on the identified theoretical gaps, cultural considerations, and the unique characteristics of Almaty’s IT sector, this study formulates a set of research questions designed to guide the empirical investigation. The intention is to capture both the manifestations of incivility and the mechanisms through which they influence employee well-being and organizational outcomes. Given the hybrid and multilingual nature of IT work in Kazakhstan, the research questions emphasize contextual interpretation, resource dynamics, and relational processes that existing Western-centered models have not fully explored.

Accordingly, the study is guided by the following research questions:

1. **How do workplace and cyber incivility manifest in IT and digital organizations in Almaty?**
This question seeks to identify the specific offline and digital behaviors that employees perceive as rude, disrespectful, or dismissive within hybrid work environments.
2. **How are these forms of incivility associated with emotional exhaustion, job attitudes, engagement, and turnover intention, consistent with COR theory?**
This question examines whether recurring micro-incivilities contribute to the depletion of psychological resources and how such resource loss shapes employees’ motivation, satisfaction, and intention to leave.
3. **To what extent do forgiveness climate and supervisor trust buffer the negative effects of incivility?**
This question explores the degree to which relational and organizational climate factors mitigate stress responses and protect employees from the harmful effects of incivility.
4. **What contextual factors (culture, hierarchy, multilingual communication) shape the interpretation and impact of incivility in Kazakhstan?**
This question aims to understand how cultural norms, linguistic nuances, and

power-distance expectations influence employees' perceptions, coping strategies, and emotional reactions.

Together, these research questions allow the study to build a holistic, context-sensitive understanding of incivility in Kazakhstan's IT sector. They also ensure that the empirical analysis captures not only the behavioral manifestations of incivility but also the deeper cultural, relational, and psychological processes that shape its consequences. Ultimately, the answers to these questions provide the foundation for developing practical recommendations tailored to hybrid, multilingual, and culturally diverse organizational environments in Almaty.

Literature review

2.1 Understanding Key Concepts in the Field

A. Definition of Core Concepts

Workplace incivility (WI) has emerged as one of the most pervasive yet understated forms of interpersonal mistreatment in modern organizations. Defined as low-intensity, disrespectful behaviors that violate norms of mutual respect while being ambiguous in intent, WI stands distinct from overt aggression or bullying (Khan et al., 2021; Tricahyadinata et al., 2020). It encompasses subtle but corrosive acts such as ignoring, interrupting, condescending communication, or exclusion that may appear minor in isolation but accumulate over time to erode psychological safety and trust (Butt & Yazdani, 2021; Guo et al., 2020).

The phenomenon has been conceptualized across various contexts, from healthcare to education and corporate environments, revealing its adaptability and ubiquity. Pearson and Porath (2005) describe incivility as a "gateway behavior" that, if unaddressed, can escalate into aggression and hostility, thereby undermining the organizational climate. Theoretical advances have relied heavily on Conservation of Resources (COR) theory, which posits that stress arises when individuals perceive a threat to or loss of valuable personal resources such as energy, esteem, and social standing (Butt & Yazdani, 2021). Recent research has extended this understanding to include both in-person and digital manifestations, such as cyber incivility (Lu et al., 2025), highlighting the evolving nature of workplace communication and the corresponding challenges to civility.

B. Importance of Human Behavior

Understanding the behavioral dynamics underlying incivility is central to organizational behavior and leadership ethics. Human interactions form the foundation of workplace functioning, and even subtle violations of respect can have cascading consequences for morale, performance, and retention. Studies have consistently demonstrated that incivility operates as a chronic stressor that erodes employees' psychological and emotional resources (Khan et al., 2021).

At an individual level, exposure to incivility diminishes well-being, satisfaction, and engagement while increasing emotional exhaustion and counterproductive work behaviors (Butt & Yazdani, 2021; Guo et al., 2020). The stress-erosion mechanism of COR theory demonstrates that such micro-level disrespect undermines resource resilience, eventually weakening affective commitment and identification with the organization (Guo et al., 2020). Collectively, these deteriorations contribute to lower productivity, disengagement, and high turnover (Tricahyadinata et al., 2020).

At a systemic level, human behavior under stress leads to reciprocal cycles of mistreatment, a phenomenon known as the "incivility spiral" (Raza et al., 2022). When employees respond to incivility with further incivility, organizational climate deteriorates rapidly, reducing collaboration and psychological safety. Such insights highlight the importance of promoting civility as an ethical and managerial imperative rather than a mere interpersonal nicety.

C. Challenges Faced in the Field

Despite increased attention, several challenges complicate the management of workplace incivility. Its ambiguous nature often makes it difficult to identify or address formally. Because perpetrators can deny harmful intent, organizational policies frequently fail to capture its nuances, leaving victims without recourse. Moreover, the subtlety of incivility creates psychological uncertainty, forcing employees to question whether their experiences are legitimate or exaggerated (Khan et al., 2021).

Empirical evidence further shows that the effects of incivility extend beyond interpersonal discomfort. For instance, research in healthcare demonstrates that patient-to-staff incivility undermines professional confidence, teamwork, and care quality (Vargas & Mahalingam, 2020). In such contexts, power asymmetry intensifies the emotional burden on workers who cannot reciprocate or confront rude behavior. Similarly, in corporate and service industries, customer incivility generates emotional exhaustion, disengagement, and intentions to quit (Wang et al., 2022).

Another major challenge lies in the cross-cultural variability of civility norms. What is perceived as assertiveness in one culture may be viewed as rudeness in another. Thus, definitions of acceptable workplace behavior are not universal but socially constructed and context-dependent, a gap particularly relevant for underexplored cultural regions such as Central Asia.

D. Influence of Societal Factors

Societal, cultural, and organizational norms deeply influence how incivility is expressed, tolerated, and managed. Shen et al. (2023) demonstrated how macro-societal threats specifically racialized stressors during the COVID-19 pandemic altered the effectiveness of workplace diversity climates, offering “unequal protection” against incivility for Asian employees. This insight reveals that workplace behavior cannot be separated from its socio-political context.

In hierarchical and collectivist societies, like many in Asia, civility expectations often intersect with power distance and gender norms. For instance, Tricahyadinata et al. (2020) found that in Indonesian organizations, the impact of incivility on job satisfaction and turnover intention varied significantly by gender, underscoring how societal gender roles shape perceptions of mistreatment. Similarly, religious and ethical worldviews, such as Islamic Work Ethics (Raza et al., 2022), provide moral frameworks that may buffer employees against the negative effects of incivility, highlighting the cultural embeddedness of coping mechanisms.

These findings collectively underscore the need to contextualize incivility within broader socio-cultural systems, where national culture, religion, and historical legacies such as Kazakhstan’s post-Soviet hierarchy shape organizational dynamics and acceptable communication norms.

2.2 Ethics and Professional Behavior: A Critical Examination

A. Understanding Ethical Behavior in Organizations

Ethical behavior in organizational contexts refers to actions aligned with fairness, integrity, and respect for others. Incivility represents a deviation from these ethical norms, undermining the moral foundation of workplace interactions (Pearson & Porath, 2005). Within leadership ethics, civility functions as both an ethical duty and a relational competence that fosters trust and cooperation. The violation of these micro-ethical norms through ridicule, exclusion, or dismissiveness signals not only interpersonal disrespect but also an erosion of organizational justice and care ethics.

Workplace incivility, therefore, can be conceptualized as a microethical issue with macro consequences. Even though it may appear minor compared to harassment or discrimination, its cumulative impact corrodes the ethical climate of the organization, normalizing disrespect and cynicism (Butt & Yazdani, 2021). Leaders who ignore incivility implicitly condone it, creating a culture of permissiveness where unethical behavior can escalate.

B. Factors Influencing Ethical Behavior

A growing body of research identifies individual, social, and organizational factors that influence ethical conduct and responses to incivility. At the individual level, employees' psychological capital comprising resilience, optimism, hope, and self-efficacy emerges as a vital buffer (Butt & Yazdani, 2021). Workers with higher psychological resources are better equipped to interpret disrespectful acts less personally and to recover more quickly from emotional harm.

At the social level, team climate and leadership play a defining role. A forgiveness climate, a collective perception that mistakes and interpersonal transgressions will be met with understanding rather than punishment reduces the negative effects of incivility on well-being and satisfaction (Khan et al., 2021). Such climates foster resilience by reframing disrespect as an opportunity for learning and restoration rather than retaliation.

Organizational systems also exert profound influence. In environments that reward competition over collaboration, incivility often becomes normalized as a side effect of performance pressure. Conversely, organizations emphasizing empathy and ethical leadership demonstrate greater resistance to these toxic patterns (Raza et al., 2022). Hence, ethics and incivility are not opposites on a continuum but dynamically interrelated forces shaping workplace culture.

C. Cultural Norms and Their Impact

Cultural norms shape how ethical and uncivil behaviors are perceived, rationalized, and addressed. The cross-cultural variability in incivility research highlights how societal values dictate behavioral expectations. For instance, Raza et al. (2022) showed that Islamic Work Ethics (IWE) grounded in moral discipline and respect act as a powerful moderator that weakens the incivility spiral. Employees guided by strong ethical or religious values are less likely to reciprocate disrespectful acts, even when provoked.

In contrast, in secular or highly individualistic societies, civility tends to be seen as a matter of professional competence rather than moral obligation. These cultural differences suggest that interventions must be tailored to local moral frameworks. For example, in Kazakhstan a culturally hybrid society blending collectivist and hierarchical elements civility expectations may align more closely with relational harmony and respect for authority, meaning that even subtle violations can carry deep symbolic weight.

Cultural diversity also intersects with globalized digital communication norms. The rise of remote and hybrid work has introduced "cyber incivility," where tone, delays, or exclusion in digital channels can be perceived as disrespectful (Lu et al., 2025). Such challenges demand renewed ethical literacy in cross-platform communication, especially in multilingual and multicultural teams.

D. Relevant Theoretical Frameworks

Several theoretical frameworks provide structure for understanding how workplace incivility unfolds. The Conservation of Resources (COR) theory (Butt & Yazdani, 2021) remains central, framing incivility as a resource-depleting stressor that triggers emotional exhaustion and defensive responses. This framework explains why repeated exposure to low-intensity disrespect can yield severe psychological outcomes.

The Social Exchange Theory complements COR by suggesting that workplace relationships operate on reciprocity; thus, incivility disrupts these exchanges, leading to retaliation or withdrawal (Raza et al., 2022). The Justice Theory further contextualizes these interactions, proposing that perceived injustice whether interpersonal or procedural amplifies the emotional impact of uncivil acts.

Recently, cross-disciplinary perspectives such as the Diversity Climate Model (Shen et al., 2023) and Ethical Leadership Theory have added nuance by considering how structural and leadership factors mediate these experiences. Integrating these frameworks allows researchers to

connect micro-level experiences of disrespect with macro-level organizational ethics and climate, offering a multidimensional lens suitable for diverse cultural contexts like Kazakhstan.

2.3 Research Gaps

While the global literature on workplace incivility is extensive, it remains geographically and methodologically unbalanced. Most studies originate from Western and East Asian contexts, leaving Central Asia largely absent from empirical discourse. This geographical gap is significant, given the unique post-Soviet organizational hierarchies, multilingual environments, and cultural hybridization of Kazakhstan, where both collectivist and hierarchical norms coexist.

Moreover, the dominance of quantitative methods surveys and structural equation modeling limits understanding of the nuanced meanings and cultural interpretations of incivility. Quantitative designs are valuable for testing theoretical pathways, but they often overlook how employees define, rationalize, and emotionally experience incivility within their sociocultural settings. Few studies employ interpretive, qualitative approaches that could reveal the symbolic and relational dimensions of disrespect.

Another gap concerns the intersection between digital transformation and civility. With the increasing digitization of work, cyber incivility presents new challenges that traditional frameworks have yet to fully address (Lu et al., 2025). Similarly, macro-level crises, such as pandemics or geopolitical instability, have shown to alter the protective effects of organizational climates (Shen et al., 2023), yet little is known about how such external stressors operate in developing economies.

Finally, although moderating mechanisms such as forgiveness climate (Khan et al., 2021) and Islamic Work Ethics (Raza et al., 2022) have been validated, research rarely explores indigenous ethical frameworks outside the Middle Eastern or South Asian context. The lack of region-specific theories prevents effective localization of interventions in culturally distinct environments such as Kazakhstan.

Methodology

3.1 Sample Description

The study draws on qualitative data collected from 15 employees working in IT and digital services organizations in Almaty, Kazakhstan. Although the full research plan initially proposed a larger sample, the present paper reports findings from the completed interview phase involving all 15 participants. This cohort represents a diverse range of IT roles, including backend, frontend, full-stack, and software engineers, QA specialists, DevOps professionals, product managers, and mid-level team leaders operating in both local and international digital product environments. Participants varied in organizational tenure from one to ten years, with most reporting between three and five years of professional experience in their current organization. All participants worked in hybrid or fully remote arrangements, reflecting the dominant work structure of the IT sector in Almaty.

Although demographic details were not fully collected to preserve anonymity, the sample reflects the typical diversity of Almaty's IT labor market. Participants varied in gender, age (from early 20s to mid-40s), and role seniority, including junior engineers, mid-level specialists, and team leads. Several participants identified as bilingual or trilingual (Kazakh, Russian, English), which aligns with the multilingual nature of the sector. This diversity allowed the study to capture a wide spectrum of experiences across hierarchical levels, generational backgrounds, and linguistic profiles, strengthening the credibility and contextual richness of the findings.

The sample was recruited through purposive sampling, supplemented by snowball referrals. Inclusion criteria required a minimum of six months of tenure, regular engagement in digital communication platforms, and active participation in hybrid or distributed teamwork.

These criteria ensured that each participant possessed substantive exposure to both offline and cyber incivility and had sufficient contextual familiarity to describe communication norms, interpersonal dynamics, and organizational responses meaningfully.

3.2 Data Collection Methods

Data were collected through semi-structured, in-depth interviews, conducted entirely via Zoom. This method was chosen to capture the subtle, context-dependent, and affective dimensions of workplace and cyber incivility, which are difficult to assess through structured surveys alone. All fifteen interviews followed the same semi-structured protocol but allowed flexibility to probe deeper into participants' experiences and interpretations.

Interviews lasted between 10 and 20 minutes. The majority were conducted in English, which is commonly used in IT teams for technical communication and cross-border collaboration. A smaller number were conducted partially or fully in Russian, depending on the participant's comfort level. Regardless of language, all interviews explored six core domains: experiences of offline incivility, encounters with cyber incivility in digital channels, emotional and motivational consequences consistent with Conservation of Resources (COR) theory, perceptions of fairness and leadership behavior informed by LMX and organizational justice frameworks, cultural and multilingual influences specific to Kazakhstan, and participants' evaluation of organizational communication norms along with recommended improvements.

All interviews were audio-recorded with informed consent, transcribed verbatim, and, when necessary, translated into English with careful attention to preserving tone, meaning, and culturally embedded expressions. Prior to formal data collection, the interview guide was pilot-tested with two individuals to ensure clarity and cultural appropriateness. Data collection followed an iterative process, allowing for adjustments to prompts as new themes emerged.

3.3 Data Analysis Methods

Data were analyzed using thematic analysis, guided by the six-step framework outlined by Braun and Clarke (2006). This approach was selected because of its flexibility and suitability for uncovering patterns of meaning within complex, narrative data. Analysis proceeded first through repeated reading of the transcripts to achieve familiarity with participants' accounts, followed by inductive open coding. Across the 15 interviews, more than 300 initial codes were generated, capturing a range of experiences such as condescending tone in technical discussions, digital silence in team chats, passive-aggressive comments in task management systems, emotional drain after abrupt communication, perceived unfairness in leadership responses, and multilingual tone misinterpretation.

Codes were then grouped into broader, data-driven themes reflecting shared patterns across participants. These themes included stress-driven offline incivility, ambiguity and selectivity in cyber incivility, emotional resource depletion and withdrawal, inconsistent leadership responses and fairness perceptions, cultural and hierarchical influences on communication, and weak or unevenly enforced digital etiquette norms. Once the inductive structure was established, themes were interpreted deductively in relation to relevant theoretical frameworks. COR theory provided a conceptual lens for understanding emotional exhaustion and disengagement; Leader–Member Exchange (LMX) theory helped interpret variation in leader–employee relational quality; organizational justice theory explained perceptions of fairness and voice; and cultural communication theories illuminated the influence of multilingual interaction and power distance on tone interpretation.

To ensure transparency, coding decisions, theme integration, and interpretive reflections were documented through analytic memos and a structured codebook maintained in Excel. Although more advanced qualitative software such as NVivo could support similar work, the dataset size allowed for rigorous manual coding without loss of analytic depth.

Preliminary Findings

This section presents the preliminary findings from the pilot study based on qualitative data collected from 15 participants working in IT and digital services organizations in Almaty. Although the broader project aims to expand data collection, the pilot interviews already reveal strong and consistent thematic patterns regarding the manifestation of workplace and cyber incivility, emotional and behavioral outcomes, and contextual cultural influences. No quantitative data were collected at this stage, consistent with the interpretivist design of the study.

4.1 Qualitative Data: Themes and Illustrative Insights

Analysis of the 15 interviews revealed six major themes that consistently appeared across participants. These themes reflect the complex interaction between workplace behavior, digital communication, emotional well-being, leadership dynamics, and Kazakhstan's cultural context.

Theme 1: Stress-Driven Offline Incivility

Most participants described experiencing low-intensity incivility in face-to-face interactions, typically during team meetings or technical discussions. Incivility manifested in the form of abrupt criticism, interruptions, sarcastic remarks, or dismissive tone. These behaviors were often attributed not to personal hostility but to pressure associated with deadlines, releases, or cross-team dependencies. Illustrative quote: *"Not the criticism itself, but the tone — as if your work doesn't matter. It usually happens when people are stressed."*

Participants emphasized that while these incidents were not severe, their accumulated effect created emotional tension and reduced willingness to speak up.

Theme 2: Cyber Incivility as a Frequent and Ambiguous Problem

Digital communication channels Slack, Telegram, email, Jira, and Zoom were described as the primary space where incivility occurred. Participants reported experiences such as selective message ignoring, abrupt or command-like phrasing, "???" messages, passive-aggressive comments in tasking tools, and being removed or added to chats without explanation. Cyber incivility was not only more common but also more ambiguous, making it difficult to interpret intent. Illustrative quote: *"If someone ignores your message but replies to others in the same chat, it feels personal. You're never sure if it's disrespect or just workload."*

Participants agreed that ambiguity intensifies emotional strain, particularly in hybrid teams.

Theme 3: Emotional Resource Drain and Declining Motivation (COR Theory)

Repeated incidents of incivility, especially digital silence or dismissive communication led to emotional exhaustion, frustration, and perceived "resource loss." Participants described feeling drained, less motivated, and more likely to avoid interactions or limit initiative. Illustrative quote: *"You feel like your energy just leaks out. After a few such interactions, you only want to do the minimum."*

This pattern strongly aligns with Conservation of Resources (COR) theory, demonstrating how micro-incivilities accumulate into broader emotional fatigue.

Theme 4: Leadership Blind Spots and Inconsistent Fairness (LMX & Justice)

Participants consistently reported that leaders in IT teams were often unaware of low-intensity incivility, treating it as "normal for IT" or as part of a fast-paced environment. While some leaders intervened in severe cases, they rarely addressed subtle dismissive tone or digital rudeness. Several participants felt that more vocal or assertive employees received more attention

and recognition, while quieter team members were unintentionally overlooked. Illustrative quote: *“Leaders step in only when things escalate. Small rude moments just go unnoticed.”*

This theme highlights issues related to organizational justice and Leader–Member Exchange (LMX) variations.

Theme 5: Cultural and Multilingual Influences on Tone and Interpretation

A significant number of participants emphasized the role of Kazakhstan’s cultural norms, such as respect for elders, hierarchical communication, and collectivist conflict avoidance. Multilingual communication added additional layers of complexity. Participants noted that: Russian often sounds sharper or more emotional; Kazakh tends to sound more formal or soft; English is perceived as neutral and emotionally safe. Illustrative quote: *“The same message feels different in Russian and in English. Tone changes completely.”*

This theme underscores the need to interpret incivility within Kazakhstan’s multicultural and multilingual context.

Theme 6: Weak or Inconsistently Enforced Digital Communication Norms

Although most organizations had some form of communication guidelines, participants agreed that these norms were rarely enforced. Teams often relied on personal habits, leading to inconsistent expectations regarding tone, response time, and transparency.

Recommendations included establishing clearer messaging standards, training technical leads in empathetic communication, and formalizing expectations around task delegation and escalation. Illustrative quote: *“Rules exist, but no one follows them. Everyone communicates differently, and that’s why conflicts appear.”*

4.2 Sample Size Considerations and Limitations

As a pilot study, the findings are based on interviews with 15 participants, a typical sample size for exploratory qualitative research. While this number provides rich insights and strong thematic saturation, it does not allow for statistical generalization. Instead, the pilot findings serve to:

- refine the conceptual framework,
- validate the relevance of the interview guide,
- identify emerging themes for deeper investigation,
- inform hypotheses for future quantitative testing.

Any conclusions drawn from the pilot should be interpreted with caution, as experiences may vary across other IT organizations and demographic groups. Nonetheless, the strong consistency across participants suggests that the identified patterns likely reflect broader dynamics within Almaty’s IT and digital services sector.

Analysis of Findings

The qualitative analysis of fifteen in-depth interviews revealed a complex set of relational, emotional, and cultural dynamics underlying workplace and cyber incivility in Almaty’s IT sector. Using thematic analysis, the interviews were examined for recurring patterns, discursive markers of disrespect, emotional interpretations, and contextual influences shaping how incivility is perceived and managed. The findings are interpreted in the context of the study’s research questions and theoretical frameworks, particularly Conservation of Resources (COR) theory, Leader–Member Exchange (LMX), and cross-cultural communication literature.

A central finding is that both workplace and cyber incivility emerge not as intentional aggression, but as subtle, ambiguous, and often stress-induced behaviors embedded in the tempo of IT work. Many participants described offline incivility as occurring during high-pressure project phases, where colleagues or managers interrupted discussions, dismissed ideas without

explanation, or used a sarcastic tone. Although participants rarely attributed malicious intent to these behaviors, the emotional impact was significant. One interviewee explained, “It wasn’t what he said, it was how quickly he shut me down. It felt like my opinion didn’t matter.” Such experiences resonate with interactional justice theory, suggesting that employees are sensitive to the quality of interpersonal treatment irrespective of content.

Cyber incivility emerged even more prominently. Across interviews, employees emphasized that digital communication Slack, Telegram, email, Jira created conditions for misunderstandings. Short, context-less replies, abrupt command-like messages, selective ignoring, and unexplained removal from task threads were frequently cited. Participants highlighted that digital silence was one of the most emotionally taxing forms of incivility. Several interviewees distinguished between workload-based delay and intentional avoidance by observing response patterns across channels. As one respondent noted, “If they’re active in other chats but ignore your question for hours, it feels personal, even if maybe it isn’t.” This aligns with prior research on cyber ambiguity, where lack of contextual cues amplifies negative interpretations.

The emotional consequences of these behaviors were substantial and aligned strongly with COR theory. Participants consistently described experiences of resource depletion: heightened stress, emotional fatigue, reduced motivation, and temporary withdrawal from collaborative tasks. Many reported that recurring incivility “drains energy” or “kills initiative,” with one participant stating, “After a few days of this, you stop wanting to speak up, you just do your minimum.” This pattern echoes empirical findings that micro-incivilities accumulate over time, producing emotional exhaustion and reduced engagement. While a single episode rarely prompted thoughts of resignation, prolonged exposure or normalization of rude behavior within a team often led employees to consider leaving their department or the organization.

Leadership behavior played a critical role in shaping employees’ interpretation and response to incivility. Many interviewees felt that managers overlooked subtle incivility because it blended into a fast-paced IT culture. Only explicit conflict typically triggered managerial intervention. Several participants emphasized that trust in the supervisor acted as a buffer: when the leader was perceived as fair and supportive, employees interpreted rude messages from colleagues less negatively. Conversely, when trust was low, even minor slights were magnified, creating LMX-based asymmetries. One respondent articulated this dynamic: “If you trust your manager, you think, okay, it’s stressful. If not, you take every comment to heart.”

Cultural and linguistic factors further shaped perceptions of incivility. Many participants highlighted that messages written in Russian often sounded harsher, while Kazakh could feel more formal or indirect. English was frequently described as emotionally neutral and “safe,” especially for difficult conversations. Additionally, Kazakhstan’s hierarchical culture influenced employees’ reactions: criticism or abruptness from older or senior colleagues was perceived as more disrespectful, while expressing disagreement upward was often avoided due to fear of being seen as rude. These findings reinforce the notion that incivility cannot be understood without considering local cultural norms around respect, power distance, and communication style.

Another significant pattern was the inconsistency of organizational norms related to digital communication. Although most companies had formal guidelines or etiquette policies, participants reported that these rules were rarely enforced or even remembered in everyday practice. As a result, teams often operated based on informal norms shaped by project urgency, individual personality, or dominant team members. The absence of shared expectations increased the likelihood of misinterpretation and emotional strain. Several participants recommended clearer rules regarding response times, tone, and expectations for context in task assignments.

Taken together, the findings illustrate that workplace and cyber incivility in Almaty’s IT sector are rooted in a combination of workload pressures, digital ambiguity, cultural sensitivities, and leadership practices. Thematic patterns closely align with international research but also

display contextual nuances specific to Kazakhstan’s multilingual, hybrid, and hierarchical work environment. The results support COR theory by demonstrating how subtle disrespectful behaviors deplete emotional resources and reduce engagement. They also validate the buffering effects of supervisor trust and a forgiving team climate, which help employees reinterpret or emotionally recover from negative interactions.

Overall, the analysis highlights that incivility is not merely an interpersonal issue but a systemic organizational challenge shaped by communication norms, cultural expectations, leadership behavior, and team climate. Understanding these interconnected elements is essential for designing interventions that address not only behavior but also the underlying relational and structural conditions that allow incivility to persist.

Table 1. Summary of Emergent Themes and Theoretical Connections

Theme	Description Based on Participant Narratives	Theoretical Link	Illustrative Quotes
1. Stress-driven offline incivility	Incivility often occurred during high-pressure periods such as releases or sprint deadlines. Behaviors included interruptions, sarcastic comments, dismissive tone, and undervaluing contributions. Employees typically viewed these acts as stress-induced rather than intentional.	Interactional Justice; LMX (leader–member relational quality influencing interpretation of tone).	“It wasn’t the criticism — it was how fast he shut me down.” • “During releases everyone is tense, and people forget to be polite.”
2. Cyber incivility and digital ambiguity	Digital communication (Slack, Telegram, Jira, email) amplified misunderstanding due to missing nonverbal cues. Selective ignoring, short commands, unclear assignments, and passive-aggressive comments were most common.	Cyber Incivility Frameworks; Social Presence Theory; Digital Communication Ambiguity.	“If they’re online but ignore your message, it feels personal.” • “Short replies without context feel rude, even if they didn’t mean it.”
3. Emotional exhaustion and resource depletion (COR)	Participants described emotional fatigue, reduced motivation, and temporary withdrawal from collaboration as incivility accumulated. People became more cautious, avoided proactive communication, or limited contributions to minimum tasks.	Conservation of Resources Theory (Hobfoll).	“It drains your energy.” • “After a few days of this you stop wanting to speak up.”
4. Leadership blind spots and fairness concerns	Managers often overlooked subtle incivility or intervened only in explicit conflicts. Employees felt that “louder” colleagues received more attention. The supervisor trusts moderated reactions to rudeness.	Organizational Justice; LMX; Trust and Psychological Safety.	“If you trust your manager, you assume it’s stress. If not, every comment feels like an attack.” • “Quiet people get ignored.”

5. Cultural and multilingual influences	Tone shifts across languages influenced perceived rudeness. Russian sounded harsher, Kazakh more formal, and English more neutral. Power distance made upward feedback and disagreement more sensitive.	Cross-Cultural OB; Hofstede (power distance); Language and Tone Perception.	"The same message sounds different in Russian vs English." • "People avoid giving direct feedback to senior colleagues."
6. Inconsistent digital communication norms	While companies had formal etiquette rules, they were rarely applied consistently. Teams lacked shared expectations for tone, response times, and clarity, increasing misinterpretation.	Communication Climate; Norms Theory; Organizational Culture.	"We have rules, but no one follows them regularly." • "If everyone had the same expectations, half of the conflicts wouldn't happen."
7. Forgiveness climate and relational repair	Teams were generally quick to "reset" after tense moments. Informal apologies or humor helped. But chronic offenders developed reputational labels (e.g., "toxic").	Forgiveness Climate; Affective Events Theory (emotion recovery).	"People forgive quickly, but they don't forget patterns." • "One apology is enough — unless it happens every week."

Table 1 presents a synthesis of the key themes that emerged from the thematic analysis of the 15 qualitative interviews. Each theme reflects a distinct dimension of workplace or cyber incivility experienced by IT professionals in Almaty's hybrid and multilingual work environments. The table integrates participants' narratives with established theoretical frameworks, illustrating how subtle relational tensions, digital ambiguity, leadership practices, and cultural norms interact to shape perceptions of respect and incivility. The inclusion of illustrative quotes highlights the lived realities behind the themes, demonstrating the emotional and cognitive processes employees undergo when encountering uncivil behavior. Collectively, these themes provide a structured foundation for understanding how incivility unfolds, how employees interpret it, and which organizational mechanisms intensify or mitigate its effects.

Table 2. Mechanisms of Workplace and Cyber Incivility: Manifestations, Outcomes, Buffers, and Contextual Modifiers

Category	Description	Illustrative Examples from Interviews	Theoretical Link
Manifestations of Workplace Incivility (Offline)	Subtle, low-intensity disrespect occurring during meetings or collaborative work. Often stress-driven rather than intentional.	Interruptions; dismissing ideas prematurely; sarcastic tone; public corrections in meetings.	Interactional Justice; Affective Events Theory
Manifestations of Cyber Incivility (Online)	Ambiguous or abrupt digital communication that feels disrespectful due to lack of context or tone cues.	Selective ignoring; short or command-like replies; unclear task assignments; passive-aggressive comments in task boards; “???” messages.	Cyber Incivility Framework; Media Richness Theory
Emotional Outcomes	Employees experience emotional depletion, frustration, loss of motivation, and cognitive distraction.	Feeling “drained,” “annoyed,” “unappreciated”; reduced willingness to speak in meetings; emotional fatigue after repeated episodes.	COR Theory (resource loss); Stress–Strain Models
Behavioral Outcomes	Withdrawal from collaboration, reduced extra-role behavior, disengagement, and in some cases turnover intentions.	Avoiding Slack discussions; limiting communication to short answers; stopping proactive ideas; thoughts about switching teams.	Withdrawal Behavior Literature; Organizational Commitment Theory
Cognitive Outcomes	Increased sensitivity to tone, negative attribution bias, and perception of unfairness or disregard.	Interpreting neutral messages as rude; believing one’s contributions are undervalued; viewing team members as careless or dismissive.	Attribution Theory; Organizational Justice
Relational Buffers: Supervisor Trust	Employees interpret uncivil incidents more leniently when trust in leadership is high.	“If you trust your manager, you think it’s stress. Otherwise it feels like a personal attack.”	LMX Theory; Trust and Psychological Safety
Relational Buffers: Forgiveness Climate	Teams that quickly “reset” and acknowledge stress recover faster from conflicts.	Informal apologies; humor after tension; “let’s start from scratch” attitudes.	Forgiveness Climate; Affective Events Theory

Structural Buffers: Clear Communication Norms	Explicit digital etiquette reduces misunderstandings and emotional load.	Agreed response-time expectations; unified tone standards; structured task assignment rules.	Norms Theory; Organizational Communication Climate
Structural Buffers: Workload Management	When workload is balanced, incivility declines. Chaos increases tension and rude behaviors.	Fewer rude interactions outside peak releases; respectful tone increases when deadlines are realistic.	Job Demands–Resources (JD-R) Model
Contextual Modifiers: Power Distance	Hierarchical expectations shape interpretations of incivility and reluctance to confront seniors.	Hesitation to correct older colleagues; treating senior abruptness as more damaging.	Hofstede Power Distance; Cultural OB
Contextual Modifiers: Multilingual Communication	Tone varies across languages, affecting perceived respect.	Russian is perceived as harsher; Kazakh as more formal; English as neutral and “safe.”	Sociolinguistics; Cross-Cultural Communication
Contextual Modifiers: Hybrid Work Patterns	Hybrid teams rely heavily on digital channels, which increases ambiguity and the likelihood of cyber incivility.	Misunderstandings in Slack replacing quick clarifications from office discussions.	Hybrid Work Literature; Media Synchronicity Theory

As illustrated in Table 2, the mechanisms of workplace and cyber incivility in Almaty’s IT organizations operate across interconnected levels. Incivility manifests through both offline and digital behaviors, but the emotional and behavioral impacts are disproportionately amplified in online communication due to ambiguity and reduced contextual cues. These outcomes align with COR theory, as employees consistently described resource loss, emotional exhaustion, and withdrawal. However, relational and structural buffers, particularly supervisor trust, team forgiveness climate, and clear communication norms significantly mitigate negative effects. Cultural and linguistic factors further shape how incivility is interpreted, emphasizing the need for context-sensitive interventions rather than global, one-size-fits-all civility programs.

Discussion

The purpose of this study was to explore how workplace and cyber incivility manifest in Almaty’s IT sector, how they influence employee well-being and organizational outcomes, and which relational and contextual factors shape these experiences. The findings offer both convergence with established international research and unique insights rooted in Kazakhstan’s cultural, linguistic, and hybrid work environment.

6.1 Comparison with Prior Research

The results strongly align with existing studies showing that incivility is typically subtle, ambiguous, and often unintentional (Cortina et al., 2001; Pearson & Porath, 2005). Consistent with prior work, participants frequently described micro-level behaviors interruptions, dismissive tone, delayed or selective digital responses that accumulate over time to create emotional strain

(Hershcovis, 2011; Namin et al., 2021). The prominence of cyber incivility mirrors global trends in remote and hybrid work contexts, where digital communication increases ambiguity and decreases social cues (Lu et al., 2025; Ju & Pak, 2025).

The findings also align with Conservation of Resources (COR) theory, which posits that repeated exposure to disrespectful behaviors depletes emotional and cognitive resources, leading to emotional exhaustion and withdrawal (Hobfoll, 1989). Participants' descriptions of "drained energy," reduced engagement, and hesitancy to contribute are consistent with COR-based models in incivility research (Guo et al., 2020).

However, several themes reveal culturally specific patterns that diverge from the predominantly Western literature. For example, linguistic differences Russian perceived as harsher, Kazakh as formal, and English as neutral were uniquely salient, suggesting that multilingual communication adds an additional interpretive layer not typically captured in international research. Similarly, Kazakhstan's higher power-distance norms intensified the emotional impact of incivility from senior colleagues and reduced employees' willingness to engage in open conflict or clarification. These nuances indicate that incivility in collectivist, post-Soviet contexts may carry different meanings, consequences, and coping strategies compared to Western settings.

6.2 Theoretical Implications

The findings contribute to organizational behavior theory in several ways. First, the study extends COR theory by demonstrating how resource loss occurs not only through explicit disrespect but also via digital ambiguity: employees read meaning into silence, short replies, or inconsistent communication patterns. This suggests that in hybrid IT environments, "resource erosion" may occur even without interpersonal intent, simply through unclear digital norms.

Second, the results reinforce the importance of relational frameworks such as Leader–Member Exchange (LMX). Trust in supervisors shaped how employees interpreted incivility those in high-LMX relationships viewed rude behaviors as situational, while those with lower trust perceived the same behaviors as personal or unfair. This aligns with studies showing that LMX moderates the psychological impact of workplace mistreatment (Henderson et al., 2008).

Third, the study offers new insights into the forgiveness climate as a buffer. Participants described informal mechanisms, quick apologies, humor, emotional resets that mitigated the emotional toll of incivility. This extends research suggesting that forgiveness climates reduce interpersonal tension and facilitate recovery after negative workplace events (Fehr & Gelfand, 2012).

Finally, the cultural themes hierarchy, multilingual tone shifts, and politeness norms highlight the need for OB theories to integrate cultural-linguistic dimensions when examining incivility. Western models often assume direct communication norms, whereas employees in Kazakhstan interpret tone through a culturally specific lens shaped by respect for elders, formal hierarchies, and linguistic variation.

Importantly, these mechanisms are not abstract but visibly entangled with the hybrid, multilingual, post-Soviet context of Almaty's IT sector. From a COR perspective, high workload, 24/7 digital connectivity, and blurred boundaries between home and work mean that even "small" ambiguous messages in Slack or Telegram arrive on an already depleted resource base. LMX differences help explain why the same terse comment in Russian or English was appraised either as neutral efficiency or as humiliating: when the relationship with the leader was strong, participants interpreted ambiguity as situational; when it was weak, they framed it as injustice. Interactional justice theory further clarifies why digital silence in high power-distance hierarchies felt especially threatening: unanswered questions from a senior engineer or team lead were read as a signal that one's contribution did not matter. In this way, culture (hierarchy, conflict

avoidance, respect for elders) and multilingual communication do not replace COR, LMX, or justice frameworks, but specify the conditions under which resource loss spirals, fairness concerns, and relational asymmetries are triggered in Kazakhstan.

6.3 Practical Implications

The study offers clear insights for organizations aiming to reduce incivility and strengthen workplace climate. First, given that cyber incivility was far more prevalent than offline incivility, companies should establish explicit digital communication norms, including expectations for tone, context, and response times. Even simple measures, such as guidelines on when to use “requests” vs. “commands,” can significantly reduce ambiguity.

Second, leadership training should emphasize early detection of subtle incivility and the importance of modeling relational respect. Managers often overlooked low-intensity incivility, perceiving it as part of IT’s “fast-paced culture.” However, the study shows that these small behaviors carry significant emotional consequences for employees.

Third, organizations should cultivate a forgiveness climate by creating safe channels for clarification, encouraging micro-apologies, and reducing stigma around emotional expression. This is particularly important in hierarchical cultures where direct confrontation is avoided.

Finally, multilingual communication should be explicitly addressed. Teams may benefit from neutral-language communication (often English in IT), as well as training on tone sensitivity across languages. Clear linguistic norms can help mitigate misinterpretation and support cross-cultural teamwork.

6.4 Reasons Behind Observed Trends

Several underlying mechanisms explain the patterns observed in the data. High workload and time pressure created environments where employees defaulted to abrupt communication, which was then interpreted as incivility. Hybrid work amplified ambiguous interactions, making silence or minimal replies more emotionally charged. Cultural norms around hierarchy made upward communication sensitive and increased the emotional weight of incivility from senior colleagues. Finally, inconsistent application of formal communication rules left teams without shared expectations, increasing the likelihood of friction.

6.5 Limitations and Directions for Future Research

This study has several limitations. First, the sample size fifteen participants provides depth but limits generalizability. A larger sample or multi-organizational design would strengthen the representativeness of the findings. Second, the reliance on self-reported experiences may introduce recall bias or social desirability bias, especially in hierarchical workplaces. Third, interviews were conducted in both English and Russian, which may have affected nuance despite careful translation. Future studies could analyze interactions directly (e.g., Slack logs) to compare perceived vs. actual communication patterns.

Finally, future research could adopt a mixed-method design, combining qualitative narratives with quantitative measures of resource depletion, emotional exhaustion, or LMX quality. Longitudinal designs would also help examine whether incivility escalates over time or shifts with organizational changes, such as new leadership or workload adjustments.

Conclusion

This study explored how workplace and cyber incivility manifest within Almaty’s IT and digital sector, how these behaviors impact employees’ emotional and behavioral outcomes, and what organizational factors mitigate or exacerbate their effects. Findings showed that incivility is

largely subtle, ambiguous, and often unintentional, rooted in workload pressure, hybrid digital communication, and Kazakhstan's hierarchical and multilingual work culture.

Both offline and online forms of incivility contributed to emotional resource depletion, reduced motivation, and withdrawal from collaboration, consistent with Conservation of Resources (COR) theory. Cyber incivility, particularly digital silence, abrupt tone, and unclear messages was the most prevalent and emotionally taxing. Leadership dynamics significantly shaped employees' interpretations of incivility: trust in supervisors softened negative reactions, while inconsistent managerial involvement intensified frustration. Cultural factors, including respect for hierarchy and language-induced tone variation, further influenced how employees perceived and responded to incivility.

The study contributes theoretically by extending OB and incivility literature into a non-Western, multilingual context, demonstrating how digital ambiguity and cultural norms interact to shape resource depletion and coping. Practically, the study highlights concrete interventions, communication norms, leadership training, forgiveness climate, and improved workload design that can reduce the emotional burden on employees and improve organizational climate in Kazakhstan.

Several limitations should be acknowledged. The sample size, while sufficient for qualitative depth, limits generalizability. The reliance on self-reported experiences may introduce recall or social desirability bias, especially in hierarchical organizations. Language translation between English and Russian could also influence nuance. Future research should expand the sample, integrate observational or digital communication data, and consider mixed-methods or longitudinal approaches to track changes in incivility over time.

Despite these limitations, the study provides a meaningful foundation for understanding how incivility operates within Kazakhstan's evolving digital economy. It offers theoretical advancement and actionable insights for building healthier, more respectful, and more resilient hybrid workplaces where communication clarity, cultural sensitivity, and relational trust become central components of organizational success.

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Chemical Sciences

IMPROVEMENT OF KUMYS PRODUCTION TECHNOLOGY BASED ON DRY SAUMAL

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Abstract

The article discusses the technological features of kumis production based on reconstituted dry saumal. The parameters of fermentation, the influence of temperature regimes and fermentation duration on the formation of the organoleptic and physicochemical properties of the drink are investigated. Data on the optimisation of starter cultures are presented, and conditions are determined that ensure the production of a product comparable in quality to traditional kumis made from fresh mare's milk. The stability indicators and shelf life of the finished beverage under various temperature conditions are studied. The results confirm the promise of using dry saumal for the industrial production of kumis and expanding its geographical distribution.

Keywords: kumis, dry saumal, fermentation, lactic acid bacteria, yeast, organoleptic properties, production technology, storage, reconstituted milk

Kumys is a unique fermented milk product with high nutritional value and probiotic properties, traditionally obtained by fermenting fresh mare's milk. It is widely used in traditional medicine and is considered beneficial for strengthening the immune system, normalising digestion and improving metabolism. However, its production is associated with a number of difficulties, such as the limited shelf life of fresh mare's milk, the complexity of transportation, and seasonal fluctuations in production [1].

Scientific study of the fermentation processes of dry saumal is a pressing task, since kumis is a product with special biochemical and microbiological characteristics. When switching from fresh milk to dry milk, it is important to ensure that the unique composition of amino acids, vitamins and microelements is preserved. In addition, it is necessary to study the effect of dry milk reconstitution technology on the activity of lactic acid bacteria and yeasts involved in fermentation [2].

The use of dry saumal in the production of kumis will not only simplify the logistics and storage of raw materials, but also expand the geography of its production. This opens up new opportunities for the introduction of technology on an industrial scale, as well as contributing to the development of new types of fermented products based on mare's milk [3-5].

The research hypothesis is that the use of dry saumal, subject to certain parameters of restoration and fermentation, will make it possible to obtain kumis that is not inferior in its physical- chemical, organoleptic and probiotic characteristics to the traditional drink. Thus, the development of a technology for producing kumis from dry saumal is a relevant scientific task of both theoretical and practical importance.

There are a number of patents in Kazakhstan and internationally in the field of developing technologies for producing kumis from dry saumal. These patents are aimed at improving

methods for processing mare's milk, improving its shelf life and expanding the forms in which the product is released. For example, the patent for the production of saumal in capsules (Patent KZ U7181) describes a method for obtaining dry saumal powder from fresh mare's milk, followed by packaging in capsules. The resulting product retains its vitamin content and is intended to strengthen the human immune system [6].

Along with the above-mentioned works, there are international developments, such as the method for producing kumis (Patent RU2355174C2). The invention relates to the dairy industry and involves the use of fresh mare's milk, which is fermented with constant stirring. This method is aimed at improving the quality of kumis and its stability during storage. The Kumis Product Development (Patent RU2553535C1) describes a method for producing kumis using specific starter cultures and fermentation conditions, which allows obtaining a product with specified organoleptic and physicochemical properties [7, 8].

It should be noted that in Germany there are patents not for kumis or mare's milk itself, but for methods of their production, for example, from dry powder or in encapsulated form. Thus, patent activity in the field of mare's milk processing and kumis production is aimed at developing new forms of release, improving preservation methods and expanding the functional properties of the product, which contributes to its popularisation and accessibility to a wide range of consumers.

In accordance with the above data and analysis, we conducted a series of studies to develop a technology for preparing kumis from dry saumal, which is a promising direction capable of solving a number of production problems. The use of dry milk allows for an increase in the shelf life of raw materials, greater production stability, and makes the drink accessible to a wider range of consumers.

During the experiments, samples of dry saumal obtained by spray drying were used. The starter culture consisted of a combination of lactic acid bacteria (*Lactobacillus delbrueckii* subsp. *bulgaricus*, *Lactococcus lactis*) and yeast (*Saccharomyces cerevisiae*). Control samples were prepared from fresh mare's milk.

The following analysis methods were used to assess the quality of kumis and study the fermentation processes:

1. Physical and chemical analysis. The physical and chemical properties of the beverage play a key role in determining its quality. The analysis included: Determination of acidity (pH meter): allows you to control the degree of fermentation and evaluate microbiological activity. Determination of the mass fraction of protein (Kjeldahl method): allows the preservation of the amino acid composition of kumis to be assessed. Determination of fat content (Gerber method): allows the stability of the fat fraction of the beverage to be monitored. Measurement of carbohydrates (Lein-Einon method): necessary for analysing the residual lactose content and ethanol formation during fermentation.

2. Organoleptic analysis. Organoleptic evaluation is carried out by experts to analyse the taste and texture characteristics of the beverage. The following parameters were evaluated: taste and aroma; checking for foreign tastes, the intensity of sour milk and yeast notes. Consistency: determination of homogeneity, presence or absence of sediment. Foaming: study of the stability of foam, which is a characteristic property of kumis.

3. Optimisation of fermentation parameters. To achieve the best fermentation conditions, an analysis was carried out of the influence of various factors on the quality of the final product: temperature regimes; study of the influence of incubation temperatures (30°C, 35°C, 40°C) on the growth of microorganisms and the acidity of the drink. Fermentation duration: analysis of changes in the composition of kumis at different time intervals (6, 12, 18, 24 hours). Starter culture composition: study of the effectiveness of various combinations of bacteria and

yeast to obtain the optimal taste and texture.

4. Storage and product stability. To assess the stability of kumis during storage, experiments were conducted at different temperatures (4°C, 10°C, 20°C). Changes in acidity, microflora activity and organoleptic characteristics were assessed during 7, 14 and 30 days of storage. At the initial stage, several types of kumis recipes were developed from dry saumal, which were carried out taking into account the physicochemical, microbiological and organoleptic characteristics of the drink. Various component ratios and fermentation parameters were studied to achieve optimal product quality. During the research, the optimal ingredient compositions were determined, as shown in Table 1.

Table 1.
Optimal composition of ingredients for developing a beverage recipe

Component	Amount (%)
Dry saumal	12
Water	88-90
Starter culture (lactic acid bacteria and yeast)	4-6
Additional probiotics (as needed)	2-3

After determining the recipe, a technology for obtaining the product was developed, described as follows (Figure 1):

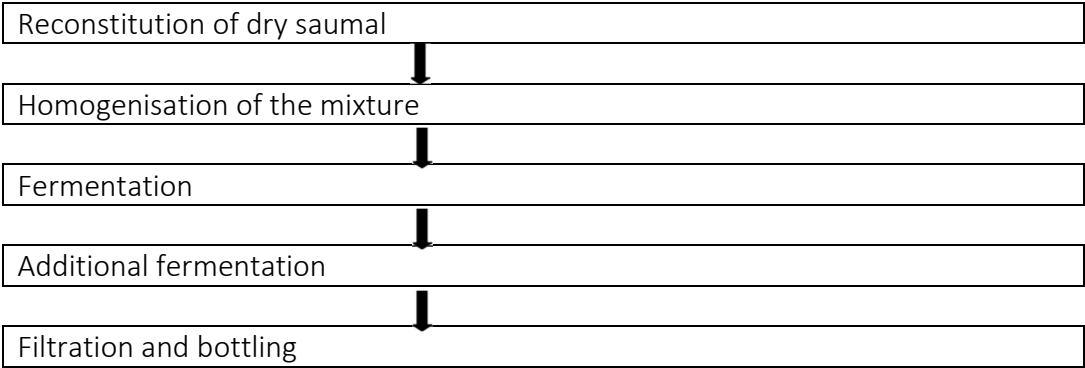


Figure 1. Preliminary process flow diagram for producing kumis from dry saumal

- 1. Reconstitution of dry saumal.** At this stage, the dry raw material is mixed with water heated to 37°C. Thorough mixing takes place until complete dissolution, which ensures a uniform start to the process.
 - 2. Homogenisation of the mixture.** The resulting liquid phase is homogenised to achieve a uniform composition, which is important for the stability of subsequent processes.
 - 3. Fermentation.** A starter culture is added to the mixture. Next, incubation takes place at a temperature of 30-35°C for 12-16 hours. This stage ensures the development of the necessary microorganisms and enzymatic processes.
 - 4. Additional fermentation.** After primary fermentation, the mixture is cooled to 5-7°C and kept for 24 hours. This allows the product to be further stabilised and the fermentation processes to be completed.
 - 5. Filtration and bottling.** Before packaging, the product is filtered to remove sediment. It is then bottled in sterile containers, which guarantees the purity and safety of the final product.
 - 6. Maturation.** The final stage involves ageing the product at 4°C for 48 hours. This allows the product to achieve the required taste and organoleptic characteristics.
- This diagram demonstrates a step-by-step approach to production, ensuring quality

control at every stage and achieving optimal parameters for the final product.

During the study, it was noted that the higher the temperature, the more the acidity of the drink changes as follows:

- At 30°C, the pH drops to 4.5 in 12 hours, and the beverage acquires a mild sourness.
- At 35°C, the pH reaches 4.2 faster, but the yeast aroma is more pronounced.
- At 40°C, fermentation accelerates, but the organoleptic characteristics deteriorate.

The results of the analysis of the physicochemical parameters of kumis from dry saumal showed that the acidity of the drink gradually increased during fermentation. The initial pH level of the reconstituted dry saumal was 6.8, but after 12 hours of fermentation it decreased to 4.7-4.9, and at the end of the process - to 4.2-4.5. This indicates the normal course of lactic acid fermentation and sufficient activity of the starter microorganisms.

The protein content of the drink ranged from 2.0% to 2.5%, which corresponds to the characteristics of traditional kumis. Determination of the fat fraction showed that its content in the final product was within the range of 1.2- 1.5%, which is due to the initial composition of mare's milk. Carbohydrate studies confirmed a significant reduction in lactose levels due to its breakdown by lactic acid bacteria and yeast.

Organoleptic evaluation showed that the drink has a pronounced sour milk taste with delicate alcohol and yeast notes. Its consistency was uniform, with no signs of sediment, and the foam formation corresponded to the established standards for kumis. Experts noted that the drink acquired its best taste properties after 18 hours of fermentation and subsequent ageing for 36 hours at a temperature of 5°C. A study of the temperature regime showed that fermentation at 28–32°C is optimal, as it promotes the active development of lactic acid bacteria and yeast. Fermentation lasting 10–14 hours ensured balanced acidity and a sufficient level of natural gas formation.

Research into various starter culture compositions confirmed that a combination of *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Lactococcus lactis* and *Saccharomyces cerevisiae* produced a beverage with optimal taste and probiotic characteristics.

The tests showed that storing kumis at a temperature of 3°C allows it to retain its consumer properties for up to 10 days without significant changes in acidity and organoleptic indicators. When the storage temperature was increased to 8°C, a more rapid increase in sour taste was observed, and at 18°C, a significant increase in acidity and the appearance of foreign flavours were observed, making this temperature unsuitable for storing the product.

Thus, the results of the study confirmed the possibility of effective production of kumis from dry saumal while preserving its traditional characteristics and beneficial properties.

Based on the results of the research, the following conclusions were made:

- Determination of the physicochemical properties of dry saumal. Studies have shown that dry saumal retains the main nutrients of fresh mare's milk, including proteins, fats, carbohydrates and vitamins.
- Development of a method for preparing raw materials. It was determined that the optimal ratio of water to dry milk is 1:9, which allows the original structure of mare's milk to be effectively restored. Homogenisation of the mixture contributed to the uniform distribution of components, which ensured fermentation stability.
- Optimisation of fermentation parameters. It has been experimentally proven that the best characteristics of the drink are achieved at a fermentation temperature of 31-36°C and a process duration of 13-17 hours.
- Comparison of kumis made from dry and fresh saumal. Organoleptic analysis showed that the drink made from dry saumal is practically no different in taste, consistency and foaming from traditional kumis.

The development of technologies for producing kumis from dry saumal opens up new prospects for the dairy industry. In the future, it is recommended to:

Research new combinations of starter cultures to improve taste and probiotic characteristics.

Develop methods to increase the shelf life of the drink without losing its beneficial properties.

To explore the possibility of introducing innovative methods of pasteurisation and packaging of kumis.

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GASIFICATION OF COAL AND BIOMASS WASTE FUEL BRIQUETTES FOR SYNGAS PRODUCTION

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Currently, municipal solid waste and waste from coal and agricultural industries constitute a significant part of the fuel and energy balance in many countries worldwide, despite the

enormous consumption of oil and gas. Coal is primarily used as an energy, chemical, and technological raw material in various industrial sectors. This natural resource represents a unique material with tremendous potential for processing. Despite the widespread availability of carbon-containing raw materials and biomass, the environmental risk associated with their use as fuel is very high, primarily due to the increased emission of harmful substances into the atmosphere during combustion.

However, it is known that environmental impact from carbon-containing waste can be significantly reduced by using upgraded, synthetic gaseous or liquid fuels obtained through chemical processing. The properties of products derived from carbon-containing waste also depend on the raw materials used in the technological processing. Many wastes are characterized by low carbon content and weak structural integrity, which limits the applicability of solid products from such wastes compared to high-rank coals. Low-rank wastes include coal slurry, some bituminous coals (grades D and G), and municipal solid waste. A distinguishing feature of these wastes is their high volatile matter content ($V_{daf} > 40\%$). Each year, increasingly stringent requirements are imposed on the utilization of carbon-containing wastes, and many countries have already introduced restrictions on their landfilling. Consequently, there is a growing societal demand for high-quality waste processing technologies. One promising solution is the thermal conversion of low-rank coals, municipal, and agricultural wastes into high-calorific fuel with low volatile matter content – a potential substitute for expensive and scarce coal grades.

We have developed a tar-free method for producing synthesis gas via the gasification of fuel briquettes prepared from coal fines and agricultural wastes, based on the “reverse thermal wave” effect. The resulting by-product process gas does not contain tar substances.

For the experiments, fuel briquettes were prepared from coal and municipal waste: 1) briquettes from “Shubarkol” coal and municipal waste in a 2:1 ratio, and 2) briquettes from “Sarykol” coal and municipal waste in a 2:1 ratio. The main stages of raw material preparation for briquetting are shown in Figure 1.





1- step	2- step	3- step	4- step
Collection of household waste	Rice husks	Dry in a drying cabinet for 1-1.5 hours.	Crushing
			

Figure 1 – Main stages of raw material preparation

The prepared briquettes (Figure 2) consisted of 80% raw materials (coal and municipal waste in a 2:1 ratio), 5% starch, 0.5% sodium hydroxide, and 15% water, which served as the binder. Water constitutes the main component of the binder. The addition of alkali during briquetting (for example, sodium hydroxide – NaOH or potassium hydroxide – KOH) performs several important functions in

the briquetting process.

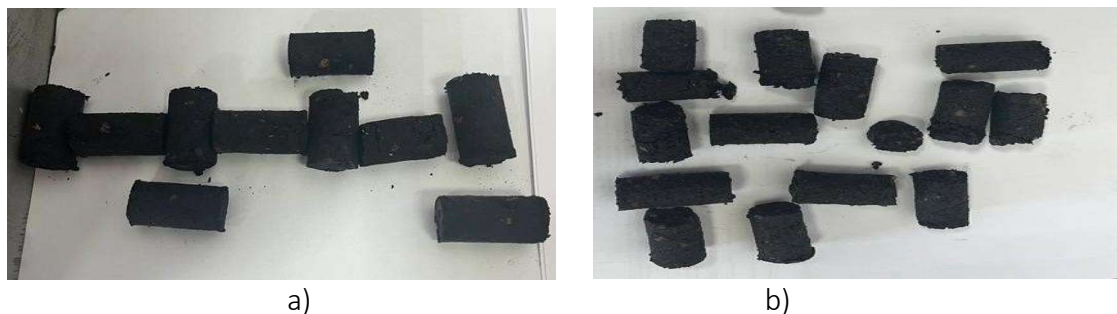


Figure 2 – Briquettes: a) made from “Sarykol” coal and biomass (rice husks),
b) briquettes made from Shubarkol coal and household waste

According to the obtained data, the lower heating value of briquettes prepared from “Shubarkol” coal and municipal waste in a 2:1 ratio is 4104 kcal/kg, indicating their high energy density. Moreover, the carbon content (47.6%) and sulfur content (0.25%) suggest their relative environmental friendliness. However, the low moisture content (7.27%) may affect combustion efficiency. On the other hand, briquettes prepared from “Sarykol” coal and rice husk in a 2:1 ratio exhibit higher moisture content (19.85%), which improves combustion quality. Nevertheless, their high ash content (25.0%) and low carbon content (38.1%) may result in lower energy output. Additionally, these briquettes have relatively low sulfur content (0.5%), reducing environmental impact.

Thus, briquettes made from “Shubarkol” coal and municipal waste feature higher heating value and carbon content, while the “Sarykol” coal and rice husk briquettes are characterized by higher moisture and lower sulfur content. The selection of briquettes should depend on the intended purpose of their use.

For gasification, dried briquettes were placed in a quartz tube of a high-temperature rotary tubular furnace BR-12NRT. The gasification process was carried out under two different temperature regimes: in an oxygen-free environment with the supply of steam at 500–700 °C, and with the supply of both air and steam at 500–700 °C.

When the temperature reached 300 °C, steam was introduced, with its temperature increasing by 20 °C per minute. The time required to reach the maximum temperature of 700 °C during gasification was 35 minutes (Figure 3).



Figure 3 – High-temperature rotary tube furnace BR-12NRT

Results of gasification of briquettes from “Sarykol” coal and household waste (2:1)

During the gasification of briquettes made from coal and municipal waste, volatile substances are released, resulting in the formation of synthesis gas. The elemental composition of the gas was determined using a “Kristallolbks 4000M” gas chromatograph. Table 1 and Figure 4 show the effect of temperature on the gas composition during gasification.

An increase in temperature leads to a significant change in gas composition. For example, at 200 °C, the hydrogen (H_2) concentration is 98.93%, indicating its predominance. However, as the temperature rises to 700 °C, the proportion of other gases increases. At 700 °C, the hydrogen concentration decreases to 26.44%, while the content of carbon monoxide (CO) and methane (CH_4) increases.

Table 1 – Gas content during gasification of briquettes (“Sarykol” coal and rice husk) with the supply of water vapor

Temperature	Content of gases released during the gasification process (%)							
	H_2	O_2	N_2	CO_2	CO	H_2S	CH_4	C_3H_8
200°C	98.93	0.04	-	1.03	-	-	-	-
300°C	99.47	0.03	-	0.50	-	-	-	-
400°C	52.31	20.0	27.31	0.18	-	-	-	-
500°C	50.30	19.37	30.33	-	-	-	-	-
600°C	45.87	16.59	16.04	17.91	3.37	-	0.22	-
700°C	26.44	6.61	16.87	28.88	8.78	1.50	10.28	0.64

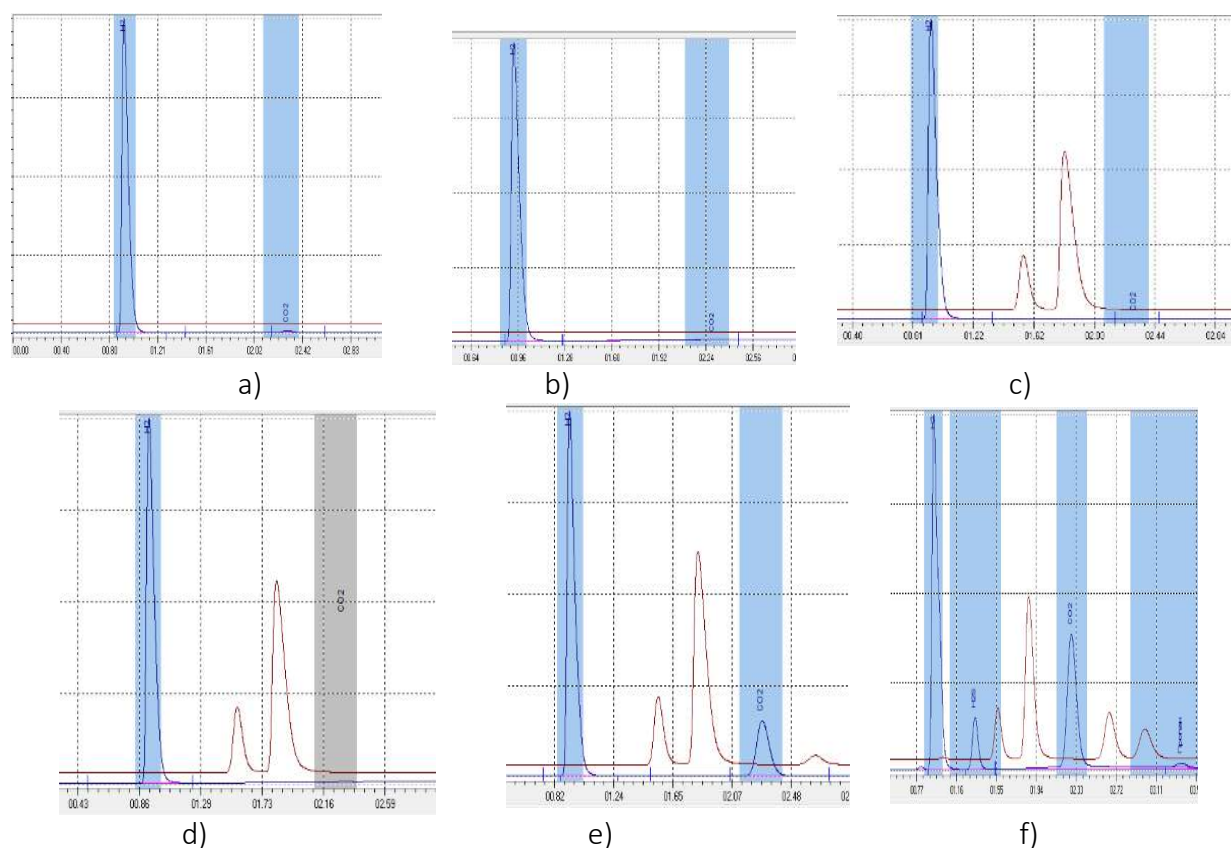


Figure 4 – Graphs of gasification of coal and rice husk briquettes in the presence of steam at different temperatures a) 200°C, b) 300°C, c) 400°C d) 500°C, d) 600°C, e) 700°C

Initially, at low temperatures (200°C and 300°C), hydrogen is the dominant component of the gas. However, as the temperature increases, the hydrogen concentration decreases, and the concentrations of other gases begin to increase. At 700°C, the hydrogen concentration decreases to 26.44%, indicating a decrease in the amount of gas as a result of decomposition and other chemical reactions. At a temperature of 700°C, the concentration of carbon monoxide (CO) is 8.78%, and methane (CH₄) is 10.28%. This indicates that high temperatures promote the formation of carbon monoxide and methane. The proportion of these gases steadily increases in the temperature range from 200°C to 700°C. Hydrogen sulfide (H₂S) reaches a certain concentration (1.50%) only at 700°C. The amount of this gas is relatively small compared to other gases, but its formation is observed at high temperatures. At temperatures of 200°C and 300°C, gases contain only hydrogen (H₂) and a small amount of oxygen (O₂). At temperatures above 700°C, gases contain complex mixtures including nitrogen (N₂), carbon monoxide (CO), methane (CH₄), propane (C₃H₈), and hydrogen sulfide (H₂S). This demonstrates that temperature has a very strong influence on the type and concentration of gases.

During the steam gasification of briquettes from “Sarykol” coal and municipal waste, increasing temperature significantly changes the types and concentrations of gases. As temperature increases, the concentration of gases such as carbon monoxide (CO) and methane (CH₄) increases, while the concentration of hydrogen (H₂) decreases. This can be adjusted depending on the demand for various gases in industrial processes.

Gasification of biomass with solid fuels (coal, sludge, and municipal solid waste) is one way to maintain competitiveness for many industries and is more environmentally friendly than direct combustion technologies. One possible and promising method for processing carbon-containing waste is gasification, which produces gas suitable for use as either energy fuel (CO, H₂, CH₄) or syngas (CO+H₂), which can be used as a feedstock for the production of motor fuels and other chemical-engineering substances. This allows for increased efficiency in the use of primary energy from solid fuels compared to direct combustion. One of the rational ways to solve social problems of energy and gas supply to small and medium-sized enterprises and remote settlements, single-industry towns, district centers, large villages and auls of Pavlodar, North Kazakhstan, East Kazakhstan, Karaganda regions, where there is no natural gas, is gasification or imported solid fuel.

It should be noted that the main problem facing cities and towns is smog caused by the excessive, uncontrolled combustion of sulfur-rich and low-grade coal in thermal power plants (TPPs), hot water boilers, and steam boilers. The main toxic components of smog are sulfur and carbon dioxide components, as well as unburned coal products.

Therefore, to address this critical environmental challenge, the current approach is to replace coal from TPPs and district boiler houses with biobriquettes produced from coal waste and biomass, synthesis gas, and supplying communities with gas. Rural areas have ample amounts of biomass from farm animals, as well as plant waste from vegetable crops, which are not recycled. This requires the implementation of biomass gasification technologies based on reliable and easy-to-use gas generators powered by locally available fuels (biomass, cattle and small ruminant waste, straw, flax stalks, etc.).

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Study of the physicochemical properties of fuel briquettes obtained from coal and biomass waste

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Abstract: The widespread use of fuel briquettes is one of the sustainable and environmentally friendly ways to generate energy. Therefore, the importance of this topic is increasing every year and is an important step towards the development of alternative fuel sources.

Relevance. Currently, the use of environmentally friendly and economical fuel sources is becoming an urgent issue in the energy sector. Traditional fuels based on coal and oil products have a significant impact on the environment and increase the emission of greenhouse gases into the atmosphere. In addition, since fossil fuels are limited, it is important to search for alternative energy sources that can effectively replace them. One of these methods is coal briquetting. As a result of briquetting, the quality and thermal performance of the fuel improves, and its heat of combustion increases. In this regard, fuel briquettes made from coal and biomass waste are one of the promising solutions.

This research work is aimed at analyzing the composition and properties of fuel briquettes made from coal and biomass waste. The main goal of the work is to study the technological features of briquette fuel production, combustion efficiency and environmental impact. In addition, the advantages and disadvantages of briquettes compared to traditional coal are identified, and the possibilities of their use as energy sources are considered.

Research object. The object of research in this work is fuel briquettes obtained from coal and biomass waste, in particular, wheat straw.

Purpose of the work: The purpose of this study is to study the physicochemical properties of solid-formed fuel briquettes obtained by adding binders from agricultural biomass waste and coal from the Maikube basin.

Main objectives:

- Selection of the optimal binder for obtaining solid-formed fuel based on biomass waste;
- Determination of the dependence of the properties of briquetted fuel on the molding conditions;
- Preparation of a sample batch of fuel briquettes based on brown coal and binder and their testing in real production conditions;
- Evaluation of the calorific value of the obtained fuel briquettes during combustion.

Practical significance: The practical significance of this research consists of several important aspects:

- Increasing energy efficiency- by studying the properties of briquettes made from coal and biomass waste, such as combustion rate, heat release capacity, and ash formation level, it is possible to improve the quality of fuel.
- Reducing environmental impact- recycling biomass and coal waste helps to reduce waste and reduce greenhouse gas emissions. Air pollution can be reduced by identifying types of briquettes that emit less sulfur and nitrogen oxides.
- Recycling and resource conservation- by reusing industrial and agricultural waste, it is possible to save natural resources and reduce the volume of coal production.
- Production of high-quality alternative fuels- studying their physicochemical properties helps to identify optimal binders and briquetting technologies, which will allow obtaining high-density, durable and efficiently burning briquettes.
- Expanding industrial application possibilities- the results of the research will serve as the basis for organizing efficient and environmentally friendly fuel production at thermal power plants, industrial enterprises, and for household needs.

This research aims to increase economic and environmental efficiency by improving the quality of fuel briquettes and therefore has great practical significance.

Introduction: Currently, there are two well-developed and widely used methods of briquetting in modern technology.

The first method is briquetting at high pressure (above 80 MPa/cm²) without the use of binders. In the CIS countries, this method is used to briquetting only small pieces of brown and hard coal using stamp presses.

The second method is the use of binders; Briquetting is carried out in roller presses at low pressing pressure (15-50 MPa/cm²). This method is universal and is used for all types of coal, anthracite, old (hard) brown coal, semi-coke and coke fines. Briquetting with binders is carried out on more productive pressing equipment and allows you to obtain briquettes with high mechanical strength.

Fuel briquettes are a type of compacted fuel produced from organic and carbon materials. Fuel briquettes can be made from all types of carbon-containing raw materials. At the same time, an important issue is also solved: the disposal of all types of combustible waste.

Coal and biomass waste mainly consist of organic substances, but their content of mineral impurities, ash, moisture, carbon and oxygen ratio varies. These features affect the combustion efficiency of the fuel and its impact on the environment. Coal-based briquette fuel allows for the effective use of fine coal waste in particular. Since fine fractions are usually unsuitable for direct combustion, their conversion into solid fuel by mixing with binding agents and pressing under high pressure is an effective and environmentally safe method. Binders are needed to prevent deformation of the compressed material and return it to its original shape. They can be added to the process or used as natural components, for example, lignin, starch, clay, molasses or wood resin, which are found in wood materials, etc. Physico-chemical processes occurring during the interaction of binding agents with coal lead to the formation of two half-layers of binding agents-adsorption and bulk layers. The adsorption-solvation layer is a fairly dense semi-layer, the thickness of which varies within 50-70% of the total film thickness.

The main raw material for the production of fuel briquettes is woodworking waste. These are sawdust, shavings, bark and other wood waste. They are obtained by sawing logs, making furniture, building wooden houses. Old boards, branches, stumps, and even leaves are suitable for production. The permissible moisture content of wood waste is up to 20%. Such briquettes have a high combustion rate and heat transfer coefficient, and they produce little smoke and ash. For example, burning 1 ton of fuel briquettes provides the same amount of energy as 1.6 tons of wood, 480 m³ of natural gas, 500 liters of diesel fuel or 700 liters of fuel oil. The process of producing fuel briquettes from biomass is multi-stage. It includes the preparation and pressing of sawdust, drying, and packaging of the finished product. To obtain high-quality fuel, it is important to observe the technology at each stage.

In addition to wood waste, the following are used for fuel production:

- straw of cereal crops (wheat, rye, rice);
- stalks of sunflower, corn and rapeseed;
- husks of sunflower and buckwheat;
- husks of nuts, seeds, beans;
- peat, reeds, paper waste.

These materials are classified as plant biomass. Some of them remain after harvesting or cleaning of seeds. The raw material is first dried to the required moisture content, and then crushed. 571 million tons of wheat are produced annually in the world, of which about 140 million tons are obtained in the form of straw. During the processing process, wheat straw accounts for about 20% of the product. The composition of wheat straw includes cellulose, hemicellulose, lignin and minerals. The amount of these components varies depending on the wheat variety, climatic conditions of the growing region, and geographical location.

The coal pressing process is the main technological operation in the production of coal briquettes. For coal briquetting, stamp, ring and roller presses are used. The presses used for briquetting are of different types and designs, depending on the charge, binder and briquetting method. The areas of application of various presses are shown in Table 1. Briquetting presses are classified according to the value of the specific pressing pressure, which is shown in Table 2:

Table 1 – Areas of application of presses

Briquetting press	Areas of application
Roller, rotary presses	Briquetting of coal, ore and ore concentrates, production waste
Stamp presses	Briquetting of young and brown coal, peat
Ring presses	Briquetting of mature old brown coal
Hydraulic presses	Briquetting of coal fines, brown coal, wood waste
Extruder presses	Briquetting of brown coal, wood waste, peat

Table 2 – Classification of presses by specific pressure

Pressing pressure	Briquetting press
Low pressure	(20 MPa- less) Extruder
Medium pressure	(20-100 MPa) Ring, roller, screening presses
High at pressure	(100-150 MPa) Stamp
At high pressure	(200-500 MPa) Hydraulic

For briquetting of brown coal, which is carried out without binding additives, stamps are mainly used. Briquettes obtained from stamp presses are used as energy fuel, as well as for subsequent thermal treatment in semi-coke and coke plants. The process of briquette formation in a stamp press is staged and consists in rapid compression of a portion of the dried material in a horizontal matrix (molding) channel by a moving stamp, in which the end surface of the previous briquette acts as a moving material. stop. The pressing pressure developed in a stamp press depends on the properties of the material being pressed and the operating conditions of the press and ranges from 800 to 1200 kg.

To obtain denser and stronger briquettes from soft brown coal for subsequent processing in semi-coke ovens, some foreign briquette factories have installations with ring presses. The briquetting process in ring presses consists of rolling finely ground material between eccentrically located cylindrical surfaces. The pressing pressure in ring presses is 1500-2000 kg.

Briquetting of small pieces of hard and old hard brown coal is carried out in roller presses with binder mixtures. The essence of the pressing process in roller presses consists in squeezing the coal charge and binder between two rollers rotating towards each other, the working surface of which is divided into cells according to the shape of the produced briquettes. The pressure generated in roller presses depends on the properties of the pressed material and the charge during coal pressing is 150-250 kg.

Briquettes obtained in roller presses are used as energy fuel for furnaces with layered combustion or are subsequently processed into smokeless household fuel.

Stamp presses are intermittent machines with an open channel. The formation of each briquette occurs in one complete reverse movement .

Forming a briquette in a stamping press involves several sequential operations: first, the dried material is fed into the molding channel, then this material is pressed into a briquette, and then the briquette belt is pushed and returned. The dried material enters the working space from the vertical loading section.

The pressing process in the stamping channel begins with the rotation of the handle, which causes the matrix to move forward. The dried material, under the influence of the matrix, is pushed

into the channel, and after the molding channel is closed, it is compressed, forming a briquette. Further movement of the crank increases the pressure of the matrix on the formed briquette to the maximum value, which eventually overcomes the resistance of the briquette strip pressed into the mold. The briquette belt moves forward by a distance equal to the width of the newly formed briquette. After that, the stamp returns to the front side.

As the crankshaft continues to rotate, the matrix begins to perform a reverse movement, first encountering the decreasing pressure of the expanding briquette, and then completely losing contact with it and returning to its original rear position.

Thus, for each revolution of the crankshaft, the stamp makes one reverse movement- it presses a portion of the dried grain into the briquette once.

The magnitude of the counterpressure, and therefore the pressing pressure, depends mainly on the friction forces that arise between the walls of the molds and the briquette strip. The friction forces, in turn, depend on the physical properties of the briquetted material.

The pressing pressure in the stamp press depends on two main factors: the counterpressure created by the friction forces in the channel and the resistance of the bracket to the movement of the briquette strip. The time of maximum pressure- the time interval between the start of the pressing process and the movement of the briquette strip- depends on the volume of the dried material being pressed and the degree of shrinkage of the coal during briquetting.

The growing demand for sustainable and eco-friendly energy sources has led to increased interest in fuel briquettes made from coal and biomass waste. Traditional fossil fuels (coal, oil) have adverse environmental impacts, releasing significant greenhouse gases, and their reserves are limited. Converting coal fines and agricultural residues into briquetted fuel can improve fuel quality (e.g. higher heating value) and reduce emissions, while also recycling waste materials. Fuel briquettes are a densified form of organic and carbon-rich materials and can be produced from a wide range of combustible residues, solving the problem of waste utilization. Two main briquetting methods exist: (1) high-pressure compaction without binder (≥ 80 MPa), and (2) binder-assisted briquetting at lower pressures (15–50 MPa). The binder method is more universal and yields mechanically stronger briquettes. In this study, we employ a binder (corn starch) to produce briquettes from a mixture of low-rank coal and biomass.

Objective: The aim of this research is to produce solid fuel briquettes from Maikube basin brown coal and wheat straw (agricultural biomass) using a natural binder, and to investigate their physico-chemical properties. The briquettes' composition, combustion performance, and environmental aspects are analyzed and compared to the raw materials. We specifically examine whether adding biomass improves combustion efficiency and emissions, and evaluate the briquettes' potential as an alternative fuel for energy production.

Materials: Brown coal from the Shoptikol deposit (Maikube coal basin, Kazakhstan) and wheat straw (collected from Pavlodar region farms) were used as feedstocks. The coal was a lignite (brown coal) ground to 0.01–0.20 mm particle size. The straw was air-dried and also milled to fine particles. A starch-based binder (corn starch) was selected as the optimal binder for briquetting, due to its natural origin and effectiveness in improving briquette strength and density. Prior to briquetting, proximate analysis of the raw materials was conducted to determine moisture, ash, volatile matter, and sulfur content, following standard procedures (GOST/ISO methods for solid fuel analysis).

Proximate and Chemical Analysis: Moisture content of the biomass was measured by oven-drying samples at 105 °C to constant weight (loss on drying). Ash content was determined by burning samples in a muffle furnace at 800 °C and weighing the residual ash. Volatile matter was measured by heating the sample in a covered crucible at 850 °C and measuring weight loss. The pH of coal and biomass samples was measured in a water slurry using a pH meter. Adsorptive capacity of the raw materials was evaluated using indicator dyes: methyl orange and methylene

blue adsorption (to assess surface activity), as well as iodine number, expressed as percentage of dye or iodine adsorbed by the sample. Total pore volume (cm^3/g) and bulk density (g/cm^3) of the materials were determined by standard techniques (e.g. mercury porosimetry or density measurement by displacement for bulk density). Elemental composition (C, H, N, S, O) of samples was analyzed with an Elementar UNICUBE CHNS analyzer.

Briquette Production: Three types of briquettes were prepared: (1) coal briquettes (from Shoptikol coal + binder), (2) biomass briquettes (wheat straw + binder), and (3) 50/50 coal-straw briquettes (coal + straw + binder in equal mass ratio). In each case, the pulverized materials were mixed with 12% binder (by weight). A small amount of water was added to form a homogeneous feed with appropriate moisture for pressing (the optimal moisture content for briquetting was determined based on achieving good compaction without excessive binder or cracking). The mixture was stirred for ~5 minutes to distribute the binder evenly. Briquettes were formed in a hydraulic press (PP-25 tablet press) by compaction in a cylindrical mold of 50 mm diameter. The pressing pressure was varied from 15 MPa up to 75 MPa to study its effect on briquette quality. Each briquette was formed into a standard size of ~50 mm height and diameter 50 mm (cylindrical shape). After pressing, the green briquettes were removed and air-dried at ambient conditions for 12–24 hours to allow the binder to set and moisture to evaporate. This drying (at ~20–25 °C) improves mechanical strength by natural curing of the starch binder.

Briquette Testing: The produced briquettes were characterized by the same methods as the raw materials. Proximate analysis (moisture, ash, volatile matter) was repeated on briquette samples. Combustion properties were evaluated with a bomb calorimeter (ABK-1V calorimeter) to measure the lower heating value (LHV) and higher heating value (HHV) of each briquette type. Additionally, an MT 027 apparatus was used to determine the auto-ignition temperature (the temperature at which the material ignites spontaneously) and the ignition temperature (the minimum temperature for ignition with an external flame) for the briquettes, coal, and straw. Elemental analysis (CHNS) was performed on briquettes to compare with raw materials.

Mechanical durability tests were carried out to assess briquette strength and water resistance. Compressive strength was measured by a uniaxial compression test: each briquette was pressed between plates until structural failure, and the maximum load was recorded. The compressive strength in MPa was calculated by dividing the failure load by the cross-sectional area of the briquette (diameter 50 mm). Water absorption was tested by immersing briquette samples in water for a fixed time (e.g. 30 s) and measuring the percentage increase in mass. This indicates the briquette's resistance to moisture (lower water uptake means higher water resistance). All experiments were repeated at least in duplicate, and average values are reported. Where relevant, results from different briquette types are compared to identify the optimal blend and conditions.

Results: Raw Material Properties: The Maikube coal (Shoptikol deposit) was identified as the best coal candidate for briquetting among several regional coals tested. Its proximate analysis showed: *ash content* ~15.3%, *moisture* ~10.9%, *volatile matter* ~6.9%, and *sulfur* ~2.4%. These values indicate a relatively low ash and sulfur content compared to other local brown coals (e.g. Sarykol coal had 17.0% ash and 3.2% S; Taldykol coal 14.8% ash and 5.0% S). Shoptikol coal's lower sulfur and ash imply cleaner combustion and less residue, so it was chosen as the coal basis for briquettes. The wheat straw biomass initially contained about 11–12% moisture (by weight) which was reduced by drying to ~3–5% before briquetting. The straw's ash content was measured around 16–17%, which is relatively high for a biomass, and volatile matter was high (~65% on dry basis, indicating most of the straw is combustible volatiles). The straw has negligible sulfur content.

Table 1 summarizes some physico-chemical characteristics of the Shoptikol coal, compared with two other coals (Sarykol, Taldykol) to illustrate why Shoptikol was selected. It also lists key properties of the prepared coal and biomass in terms of pore structure and surface activity.

Notably, Shoptikol coal had the lowest pore volume ($0.420 \text{ cm}^3/\text{g}$) and highest bulk density (0.644 g/cm^3) among the coals. A lower pore volume (less porosity) and higher density mean the material can form denser, stronger briquettes and may have higher energy density. The coal's pH was neutral (pH ~ 7.3), which is favorable for long-term stability (neutral pH is less corrosive). In contrast, another coal (Sarykol) had a larger pore volume ($\sim 1.01 \text{ cm}^3/\text{g}$) and lower density (0.533 g/cm^3) with an acidic pH ~ 4.8 , indicating a more porous and reactive structure less ideal for briquetting. The straw biomass itself, after drying and grinding, was very porous and lightweight. Its pH was near-neutral ($\sim 6.5\text{--}7$). The adsorption activity tests showed that Shoptikol coal could adsorb $\sim 25.5\%$ of methyl orange dye, $\sim 41.5\%$ of methylene blue, and $\sim 35.6\%$ of iodine (relative to its weight). These relatively high adsorption values suggest a good internal surface area and reactivity of the coal, which is beneficial for binder adhesion. The straw showed even higher adsorption for some indicators (e.g. $\sim 44\%$ for methyl orange in one sample) due to its fibrous structure, but overall, both raw materials had adequate surface properties for briquetting. In summary, Shoptikol coal was deemed a suitable base and was mixed with straw (and binder) for briquette production.

Mixing time of the mixture is 5-6 min. The amount of raw materials for pressing (143 g) was determined by the need to produce standard cylindrical briquettes with a diameter of 50 mm and a height of 50 mm. The pressing of the prepared batch was carried out in a press at a specific pressure of 15 to 75 MPa. For drying, the samples were kept in natural conditions for 12–24 hours (Fig. 1).



Fig. 1 - a) Briquette from wheat straw; b) Briquette from a mixture of coal and biomass 50/50
c) Briquette from Shoptikol coal

Briquette Composition: Using corn starch as binder, solid briquettes of three types were successfully produced (Figure 1). All briquettes were visually intact and had a smooth, solid appearance after pressing and drying. The coal-only briquette appeared dark and glossy, the straw-only briquette was lighter in color (brown), and the 50/50 coal-straw briquette had an intermediate appearance. Each type of briquette was subjected to elemental analysis to determine carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) content (oxygen by difference). The results are given in Table 3.

Table 3 – Elemental composition of briquettes vs raw materials (wt% dry basis)

Sample	C (%)	H (%)	N (%)	S (%)
Coal briquette (Shoptikol)	42.46	1.21	0.86	0.575
50% Coal + 50% Straw briq.	51.86	5.21	1.32	0.161
Straw briquette	41.80	6.27	0.98	0.012
Raw Shoptikol coal (for ref)	38.80	5.02	1.15	2.27
Raw wheat straw (for ref)	30.80	5.38	1.16	0.101

From Table 3, the 50/50 coal-straw briquette achieved the highest carbon content (~51.9% C) due to the combined carbon from coal and biomass, surpassing even the pure coal briquette (~42.5% C). The mixed briquette also had a relatively high hydrogen content (~5.2% H). In contrast, the pure straw briquette contained ~41.8% C, which is lower, but it had the highest hydrogen content (~6.3% H) of the three, reflecting the high volatile and organic compounds in straw. The pure coal briquette had low hydrogen (~1.2% H) and high carbon (~42.5% C), indicating a more carbon-dense fuel but one that would release little water vapor on combustion (since H is low). Importantly, the straw briquette's sulfur content was almost zero (0.012%), showing it burns very cleanly regarding SO₂ emissions. The coal briquette contained about 0.58% S, much lower than the raw coal's sulfur (2.27% S), because the binder and added straw diluted the sulfur content and some sulfur may have been lost or rendered less volatile during processing. The 50/50 briquette had only 0.16% S, combining the low sulfur of straw and diluted coal sulfur. These results demonstrate that co-briquetting coal with biomass yields a fuel with higher overall combustibles (C+H) and significantly reduced sulfur content compared to coal alone. The mixed briquette represents an optimal balance: it retains a high carbon fraction (for energy content) while minimizing pollutants, aligning with findings in literature that blending biomass can improve the environmental profile of coal fuel.

Physical Properties of Briquettes: Key physical characteristics of the briquettes are compared in Table 3. The coal-based briquette had a bulk density of about 0.80 g/cm³, whereas the straw briquette was less dense (in the range 0.8–1.1 g/cm³, with more internal voids) and the mixed briquette had ~0.85 g/cm³ density. The straw briquette exhibited the highest porosity, with a total pore volume of ~0.45 cm³/g, nearly twice that of the coal briquette (0.25 cm³/g). This porous structure of the straw-only briquette means it is lighter and more permeable to gases, which can aid ignition but also results in lower energy density. The coal briquette, being denser and less porous (0.25 cm³/g), has a more compact structure that can store more energy per unit volume. The 50/50 briquette had intermediate porosity (~0.36 cm³/g). All briquette types showed near-neutral pH in water (around pH 6.5–7.5), indicating no strong acidity or alkalinity leaching from the binder or materials – a positive sign for handling and storage (neutral pH fuels are less corrosive to stoves/boilers). The adsorption activity of the briquettes for the indicator dyes remained fairly high. For example, the coal briquette adsorbed ~23.6% of methyl orange, while the straw briquette adsorbed between 15–30% (varied among samples). The mixed briquette had methyl orange adsorption ~20–28%, and notably high methylene blue and iodine adsorption (up to 43% and 38% respectively). The relatively higher adsorption capacity of the mixed briquette suggests it may better trap pollutants or moisture – an interesting advantage for cleaner combustion, as it might retain sulfur or tar compounds. Overall, the coal briquette was the most dense and energy-dense, the straw briquette the most porous and reactive, and the 50/50 briquette balanced these properties. All briquettes had good structural integrity after drying, with no crumbling observed, indicating the corn starch binder provided sufficient cohesion.

Table 4 – Research results

No.	Sample	Lower heating value, kcal/kg	Higher heating value (Qrs), kcal/kg	Self-ignition temperature, °C	Ignition temperature, °C
1	Briquette (Shoptikol coal)	5193	5462	455	332
2	Straw briquette	3100	3600	376	286
3	Briquette (50/50 mixture)	4136	4423	402	315
4	Shoptikol coal	4600	4979	340	265
5	Wheat straw	2981	3280	236	338

Combustion Performance: The calorific values and ignition characteristics of the briquettes were measured, and results are given in Table 4. Both lower heating value (LHV) and higher heating value (HHV) are reported for each fuel. The Shoptikol coal briquette showed an HHV of about 5462 kcal/kg, which is about 9.7% higher than the raw coal's HHV (~4979 kcal/kg). This indicates that the briquetting process (including drying and binder addition) enhanced the effective energy content of the coal fuel, possibly by reducing moisture and concentrating carbon. The straw briquette had an HHV of ~3600 kcal/kg, also higher than the raw straw's ~3280 kcal/kg. The 50/50 mixed briquette's HHV was ~4423 kcal/kg, which lies between coal and straw briquettes, but importantly, this energy content is achieved with half the coal, demonstrating the potential of biomass to supplement coal energy. The lower heating values (which exclude latent heat of water) were 5193 kcal/kg for coal briquette, 3100 kcal/kg for straw briquette, and 4136 kcal/kg for the mixed briquette. These values confirm that the coal-based briquette delivers the highest energy, but the mixed briquette still provides a substantial energy content suitable for combustion in furnaces or boilers.

Regarding ignition, the raw coal had a measured ignition temperature around 265 °C (meaning it requires that temperature to ignite with a flame) and an auto-ignition temperature of 340 °C. After briquetting, the coal briquette required a slightly higher ignition temperature (~332 °C) but had a much higher auto-ignition point (455 °C). The increase in auto-ignition temperature for the coal briquette is beneficial for safety – it is less prone to spontaneous combustion during storage. However, the higher flame-ignition threshold (332 °C) suggests it can be a bit harder to initially light than loose coal (likely because the briquette is denser and contains moisture from binder). In contrast, the straw briquette ignited at a much lower temperature (~286 °C) compared to raw straw (~338 °C), making it easier to ignite with an external flame. This is an advantage of densification: the briquetted straw lights more readily, perhaps due to its lower density and the presence of volatile-rich binder char. The straw briquette's auto-ignition temperature increased to ~376 °C from 236 °C (raw straw), which again is positive for storage safety (loose straw can self-heat and ignite at relatively low temperatures, but briquetting reduces that risk). The 50/50 mixed briquette showed intermediate behavior: ignition temperature ~315 °C, auto-ignition ~402 °C. This mixed briquette lights fairly easily while being stable in storage. Overall, briquetting improved the combustion characteristics: the briquettes burn with higher heat output than the original materials and the biomass component lowers the pollutant emissions. For instance, the coal briquette's higher heat and longer burn time than raw coal demonstrate the effectiveness of the briquetting technology in enhancing the fuel's energy quality. The straw briquette's improved heat output and lower ignition point show that even a

low-grade fuel like straw can be significantly upgraded through briquetting. The mixed briquette achieved a synergistic effect – a good calorific value with reduced emissions – making it an optimal blend of efficiency and environmental safety.

Conclusion: This work demonstrated the successful production of solid bio-coal briquettes from agricultural biomass (wheat straw) and brown coal using a natural binder (corn starch). The following major findings and conclusions can be drawn:

- **Optimal Binder Selection:** Corn starch was identified as an optimal binder for biomass-based briquettes. As a natural, agriculture-derived binder, corn starch improved the briquettes' strength, density, and combustion efficiency without introducing toxins or excessive ash.
- **Effect of Briquetting Conditions:** The properties of the briquettes were found to depend on the molding conditions. Key factors such as pressing pressure, feed moisture, temperature, and binder content significantly affected briquette quality. Through experimentation, suitable technological conditions were determined – including a compaction pressure in the tens of MPa range, ~10% moisture content, and ~12% binder – to produce robust briquettes.
- **Fuel Performance:** A pilot batch of coal-biomass briquettes was produced and tested under real conditions. The briquettes proved to be efficient as an alternative fuel, yielding higher calorific value and longer burn duration than the raw coal or biomass. This confirms the efficacy of briquetting technology in enhancing the energy quality of coal while incorporating biomass.
- **Environmental Benefits:** The briquettes showed high heat output (comparable or superior to coal alone) and reduced emissions. Co-firing biomass in the briquette lowered the overall sulfur content and likely results in less SO₂ and NO_x emissions upon burning. The briquettes ignite readily and burn efficiently, with the 50/50 coal-straw briquette providing an optimal blend of high energy and low environmental impact. Thus, these briquettes can serve as a cleaner fuel alternative.

Implementing fuel briquettes in energy production can reduce reliance on raw coal and foster the use of local renewable resources. In countries like Kazakhstan with abundant agricultural waste and coal, co-firing briquettes in power plants and industrial boilers is a promising step toward cleaner energy. It combines the high energy of coal with the carbon-neutral emissions of biomass. Overall, this study's results provide a basis for scaling up coal-biomass briquette production for practical use, contributing to both environmental sustainability and energy efficiency.

DEVELOPMENT OF BIOMASS-DERIVED CARBON ADSORBENTS FOR WATER PURIFICATION

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Abstract:

This article presents a method for producing activated carbon adsorbents from walnut biomass and rice husks using chemical activation with KOH. Carbonization and thermochemical activation were studied at various temperatures (500–900°C), and the material balance, gas composition, and adsorption characteristics of the resulting materials were assessed. SEM and TEM analyses confirmed the formation of a meso- and microporous structure with a high specific pore volume and significant surface area. The resulting adsorbents demonstrated high efficiency in removing organic matter, suspended particles, and BOD from wastewater, especially for samples with KOH (1:4 ratio). The results demonstrate the potential of using agro-industrial waste to produce highly effective sorbents in an environmentally friendly manner.

Keywords: activated carbon, biomass, carbonization, KOH, adsorption, wastewater treatment, porous structure.

Introduction

In recent decades, water pollution has become one of the most pressing environmental issues. Industrial, agricultural, and urban developments are accompanied by the release of organic and inorganic substances, including heavy metals, pesticides, and petroleum products, into water bodies. This negatively impacts human health and ecosystems by degrading water quality and disrupting biochemical processes.

Adsorption is a promising method for purifying aquatic environments due to its high efficiency, versatility, and ease of use. The effectiveness of adsorbents is determined by their porous structure, large specific surface area, and chemical activity. Traditionally, activated carbons are produced from wood, coal, or coconut shells. However, there is growing interest in biomass and agro-industrial waste, such as sawdust, nut shells, and cereal husks, which, after carbonization, form a developed porous structure.

Chemical activation with KOH or NaOH improves adsorption properties by creating meso- and micropores and modifying surface chemical groups. Optimization of activation conditions (temperature, time, and reagent ratio) ensures the production of sorbents with desired physicochemical properties.

The aim of this study is to develop and characterize activated carbon adsorbents from biomass (walnuts, rice husks) with chemical activation by KOH, and to investigate their morphology, structure, and adsorption properties, including the efficiency of wastewater treatment for organic matter, suspended particles, and biological oxygen demand (BOD).

The use of biomass to produce activated carbons facilitates environmentally friendly waste disposal and the creation of affordable and effective adsorbents for water treatment.

Materials and Methods

Adsorbent Preparation: Walnut biomass was carbonized in a tube furnace at 500°C for 2 hours under a nitrogen flow, with a heating rate of 5°C/min. The resulting biochar was ground to a powder, mixed with 200 ml of distilled water and KOH in a ratio of 8:1, stirred for 12 hours, and dried to ensure uniform KOH distribution. Next, activation was performed: heating to 180°C to remove water and volatiles, then increasing the temperature to 900°C and holding for 1 hour. The activated material was washed with water to a pH of 7.

The study utilized methods for obtaining AC, as well as methods for determining their physicochemical and main adsorption properties: moisture content, ash content, volatility, pH of the aqueous extract, bulk density, adsorption activity using methyl orange, a method for determining the total pore volume for water, elemental analysis, the BET method for determining the specific surface area of the obtained materials, methods for purifying wastewater and gas from acidic components, etc.

The following equipment was used throughout the experiment: Raman spectroscopy and Fourier transform infrared spectroscopy (FTIR) were additionally used, allowing us to determine the nature of carbon bonds, surface functional groups, and the degree of graphitization of the materials. The elemental composition, structure, and dimensionality of the samples were studied using energy-dispersive X-ray spectroscopy on a SEM (Quanta 3D 200i) with an EDAX energy-dispersive analysis attachment.

Table 1 – Material balance of carbonization and activation of walnuts (T=600°C)

№	Incoming products	Compound		№	Outgoing products	Compound	
		г	%			г	%
1	Walnut	47,25	38,65	1	Solid product (adsorbent)	35,02	28,64
2	Water	75	61,34	2	Generator gas	10	8,17
				3	Liquid products	77,23	63,17
	Total	122,25	100		Bzero	122,25	100

The material balance shows that three main types of final products are formed from 122.25 g of starting materials: solid products (adsorbent) - 28.64%, producer gas - 8.17%, and liquid products - 63.17%. The high yield of liquid and gaseous components confirms the active thermal decomposition reactions. The resulting carbon residue (adsorbent) can be used as a sorbent, filter material, or feedstock for the production of activated carbons, making the process economically and environmentally feasible.

Production of walnut-based activated carbon (adsorbent) by carbonization and activation and thermochemical activation

The material balance of the carbonization and activation process for GO at 900°C and GO impregnated with KOH, GO/KOH = 8:1, 900°C, is presented in Table 2.

Table 2 - Material balance of the process of carbonization and activation of walnuts

№	Process	г %	Incoming products		Outgoing products		
			Raw materials	Water	Solid product (adsorbent)	Liquid products	Generator gas
1	Walnut-based activated carbon, 900°C	г	200,00	250,00	114,00	49,00	37,00
		%	44,44	55,56	57,00	24,50	18,50
2	Activated carbon based on walnuts impregnated with KOH, GO/KOH = 8:1, 900°C	г	200,00	250,00	86,00	80,00	34,00
		%	44,44	55,56	43,00	40,00	17,00

Table 10 shows the material balance of the activation process for carbon material obtained from walnut shells at 900°C without impregnation and with the addition of KOH in a ratio of GO/KOH = 8:1. The input products were the feedstock and water, which constitute 44.44% and 55.56% of the total mass, respectively. After heat treatment, three fractions were obtained: porous carbon, liquid, and gaseous products. Without the addition of KOH, the yield of porous carbon was 57%, liquid products 24.5%, and gases 18.5%. With the use of KOH, the yield of solid

residue decreased to 43%, and the amount of liquid products increased to 40%. This is due to the deeper destruction of organic compounds under the influence of alkali and the formation of a developed porous structure, which improves the adsorption properties of the activated carbon. Thus, the addition of alkali enhances chemical activation, increasing the yield of liquid products but decreasing the yield of porous carbon. The process without impregnation provides a higher yield of activated adsorbent, while alkali treatment promotes the formation of a larger quantity of liquid compounds potentially suitable for further use as chemical feedstocks.

Table 3 presents data on the composition of gases released during the carbonization and activation of walnuts at 900°C.

Table 3 – Gas composition of carbonization and activation of walnuts, 900°C

№	Temperature, °C	Gas composition, %					
		H ₂	N ₂	O ₂	CH ₄	CO ₂	CO
1	200	4,24	72,52	21,21	-	0,85	-
2	300	5,631	76,01	17,88	-	0,47	-
3	400	6,02	69,42	18,36	-	7,52	-
4	500	6,87	81,25	3,45	0,99	3,21	4,85
5	600	14,15	67,25	5,85	3,65	4,45	4,25
6	700	31,93	44,42	8,96	3,75	6,36	4,42
7	800	34,45	29,52	11,45	5,25	9,75	7,52
8	900	53,66	22,88	13,62	3,65	9,35	18,75

The data in Table 3 show that with increasing temperature during walnut carbonization and activation, there is a significant change in the composition of the gas released. Increased concentrations of hydrogen, carbon monoxide, and carbon dioxide indicate active thermochemical processes occurring at high temperatures. A decrease in nitrogen and oxygen content also confirms that these gases play a less significant role in the process as the temperature increases.

Table 4 - Gas composition of carbonization and activation of walnuts impregnated with KOH, GO/KOH=8:1, 900°C

№	Temperature, °C	Gas composition, %					
		H ₂	O ₂	N ₂	CO ₂	H ₂ S	C ₃ H ₈
1	200	1,35	17,01	78,02	2,12	-	-
2	300	1,75	18,10	77,12	2,78	0,10	-
3	400	1,02	19,12	76,47	3,21	-	-
4	500	1,21	17,45	78,12	2,64	-	0.72
5	600	1,48	8,87	87,41	2,23	-	-
6	700	3,20	16,45	78,21	2,02	-	-
7	800	4,56	12,12	81,45	1,78	-	-
8	900	4,98	8,65	85,65	1,55	-	-

Table 4 data show that during the carbonization and activation of walnuts impregnated with KOH, the composition of the gas released changes depending on temperature. A significant increase in hydrogen at high temperatures indicates active thermochemical reactions. A decrease in oxygen and carbon dioxide may indicate gas redistribution during the process, while a stable nitrogen content indicates its inertness in this process. The appearance of hydrogen sulfide and propane in limited quantities highlights the complexity of the chemical processes occurring during carbonization.

Table 5 presents the thermogravimetric characteristics and elemental composition (C, S) of walnut-based activated carbon.

Table 5 – Characteristics of AU based on walnut shells

№	Name	Humidity, %	Ash content, %	Volatility, %	Elemental composition, %	
					C	S
1	Activated walnuts. 900°C	1,95	46,53	22,64	40,9642	1,1070
2	Activated walnut with KOH, Greek nut /KOH= 8/1. 900° C	1,67	38,94	18,47	79,1083	0,1875

Table 5 demonstrates that significant compositional changes are observed when walnut shell carbon is activated at 900°C and then treated with KOH. The sample obtained without alkali had a moisture content of 1.95%, ash content of 46.53%, volatile matter of 22.64%, carbon of 40.96%, and sulfur of 1.107%. After treatment with KOH (ratio 8:1), the parameters improved: moisture content decreased to 1.67%, ash content to 38.94%, and volatility to 18.47%, while the carbon content increased to 79.11% and sulfur decreased to 0.1875%.

This demonstrates that activation using KOH helps remove impurities and ash components, increases the carbon content, and improves the quality of the resulting activated carbon. SEM images illustrate the morphological changes of the walnut structure before and after thermochemical activation with potassium hydroxide (KOH) in a ratio of 8:1 at different magnifications (Figure 1).

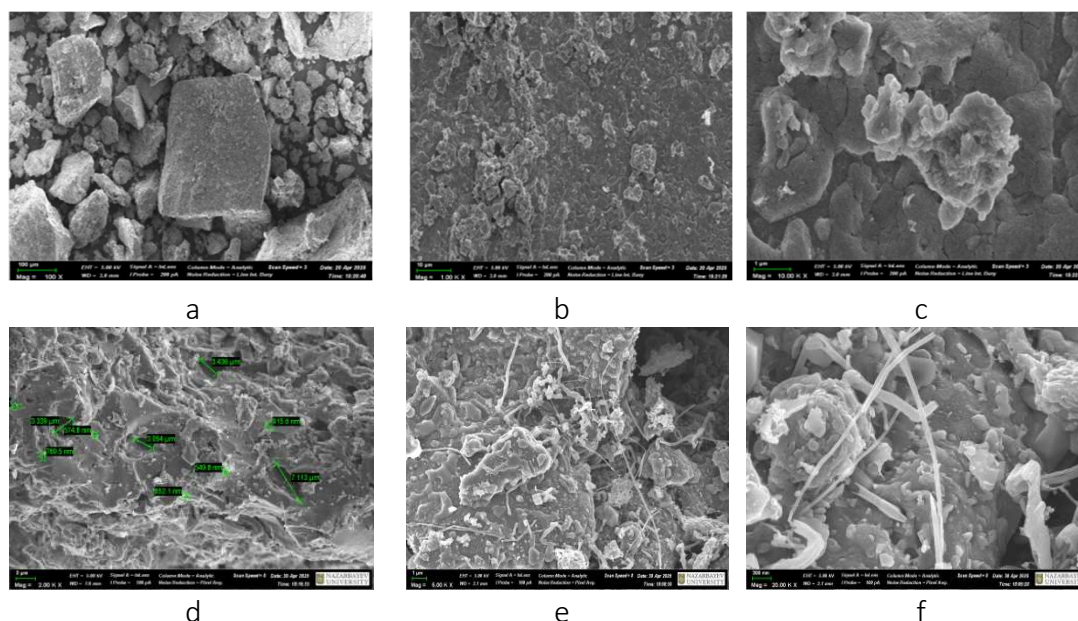


Рисунок 1 -СЭМ-изображения исходного грецкого ореха:а - $\times 100$, б - $\times 1000$, в - $\times 10000$ и АУ на основе грецкого ореха(при соотношении KOH (8:1)):г - $\times 2000$, д - $\times 5000$, е - $\times 20000$

Images a ($\times 100$) and b ($\times 1000$) show the surface of the original walnut biomass before activation. The structure is dense and uniform, with little porosity; the surface is relatively smooth. Images c ($\times 10,000$) show only isolated microcracks and pore rudiments, confirming the low degree of porous structure development in the original material.

After activation with KOH (ratio 8:1), the structure of the material undergoes significant changes. Images d ($\times 2000$) and e ($\times 5000$) show a loosened surface with the appearance of large pores and channels, indicating an intensive chemical etching process and the formation of a porous structure. At high magnification (e $\times 20,000$), developed porosity is clearly visible, as well as the formation of micro- and mesopores uniformly distributed over the particle surface. The surface becomes rough, non-uniform, and highly loosened.

After activation with KOH (8:1), the formation of pores measuring $3.054\text{--}13.38\text{ }\mu\text{m}$ (macropores) and $549.8\text{--}852.1\text{ nm}$ (mesopores) was detected. This development of the porous structure leads to a significant increase in the specific surface area, which increases adsorption capacity and makes the resulting activated carbon a promising material for use in energy (supercapacitors), wastewater treatment, filtration, and catalytic systems.

Thus, the results of the SEM analysis clearly confirm that thermochemical activation of walnut biomass with a KOH solution in an 8:1 ratio is an effective method for producing a highly porous carbon material with a developed microporous and mesoporous structure, suitable for various adsorption and electrochemical applications. Figure 2 shows transmission electron microscopy (TEM) images of activated carbon obtained from walnut shells after alkaline activation (KOH) at an 8:1 ratio. The images were taken at magnifications of 200 nm and $2\text{ }\mu\text{m}$. The images clearly reveal nanofibrillar structures, indicating the formation of carbon nanostructures during activation and subsequent carbonization.

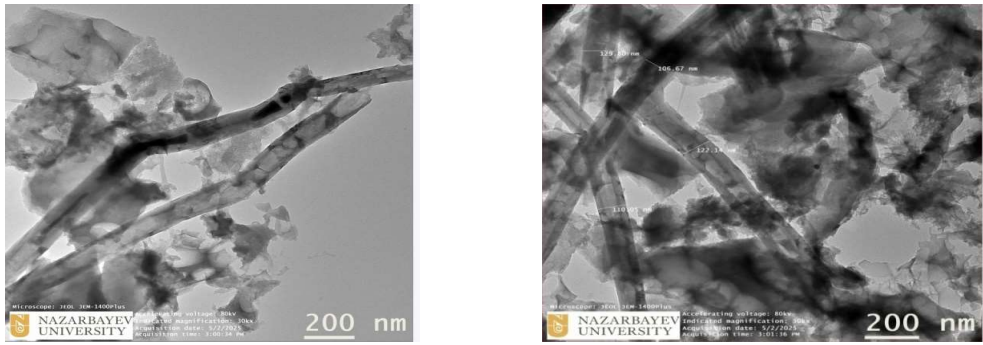
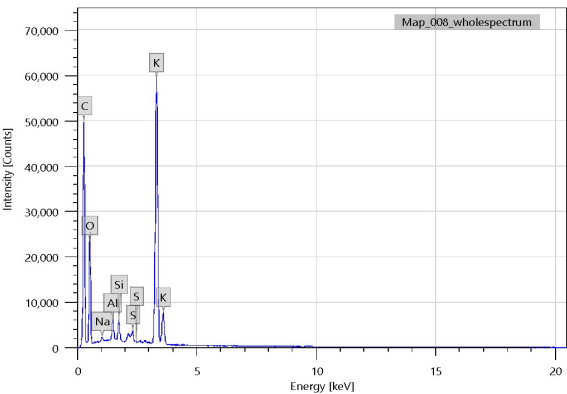


Figure 2 - TEM image of walnut-based AC (GO/KOH = 8:1)

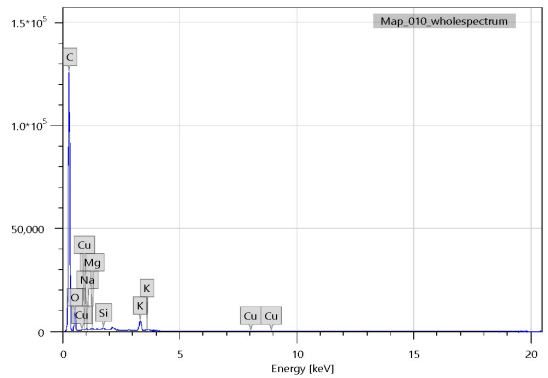
The nanofibrous morphology indicates a high degree of structural ordering and the formation of an organized carbon structure characterized by a developed surface area and pronounced porosity. This structure is particularly important for enhancing the efficiency of adsorption and electrochemical processes. It is believed that the formation of nanotubular and fibrous forms is due to the partial decomposition of the shell's organic matrix under the influence of KOH and the catalytic redistribution of carbon at high temperatures. This morphology contributes to increased electrical conductivity, improved adsorption capacity, and increased potential for the material's application in energy devices, catalysis, filtration, and electrode systems.

Thus, the results of the TEM analysis confirm that activation of walnut shells at a KOH ratio of 8:1 promotes the formation of nanofibrous carbon structures, significantly improving the morphological and functional characteristics of the resulting carbon material. This makes it promising for use in high-efficiency adsorption, catalytic and electrochemical applications.



Element	Line	Mass%	Atom%
C	K	40.02±0.04	54.08±0.05
O	K	34.24±0.09	34.73±0.09
Na	K	0.35±0.01	0.25±0.01
Al	K	1.14±0.01	0.68±0.01
Si	K	0.88±0.01	0.51±0.00
S	K	0.53±0.01	0.27±0.00
K	K	22.85±0.04	9.48±0.02
Total		100.00	100.00
Map_008_wholespectrum		Fitting ratio 0.0198	

Figure 3 – Elemental composition Akivira-based walnut carbon, 900°C



Element	Line	Mass%	Atom%
C	K	79.57±0.05	84.79±0.05
O	K	17.91±0.08	14.33±0.06
Na	K	0.16±0.01	0.09±0.00
Mg	K	0.11±0.00	0.06±0.00
Si	K	0.12±0.00	0.06±0.00
K	K	2.03±0.01	0.66±0.00
Cu	K	0.10±0.01	0.02±0.00
Total		100.00	100.00
Map_010_wholespectrum		Fitting ratio 0.0143	

Figure 4 – Elemental composition of activated carbon based on walnuts (GO/KOH = 8:1), 900 °C

Figures 3 and 4 present the results of elemental analysis of activated carbon (AC) performed using energy-dispersive spectroscopy (EDS/EDX). The study was conducted on samples obtained from walnut shells after activation with water vapor and thermochemical treatment with KOH in a ratio of 8:1 at a temperature of 900 °C. The analysis showed that carbon (C) is the main and predominant element in the composition, confirming the successful carbonization of the original raw material. The high carbon content provides the material with high electrical conductivity, chemical resistance, and developed porosity. The presence of oxygen (O) is due to the presence of surface functional groups (hydroxyl, carbonyl, carboxyl, etc.), which increase the hydrophilicity and adsorption activity of the material, especially with respect to polar substances such as heavy metals or dyes. The element potassium (K) is residual and originates from the used activator KOH. Its presence indicates incomplete leaching of the activating agent, which is typical for such systems. Moreover, a small amount of potassium can positively influence the catalytic properties of the surface. Trace amounts of other elements such as Na, Cl, and Si may be due to the natural origin of the feedstock or the specifics of activation and heat treatment. Thus, the elemental composition confirms a high degree of carbonization, the presence of functional oxygen-containing groups, and traces of activator, making the resulting carbon material promising for use in adsorption, electrochemical devices (e.g., supercapacitors), and as a catalytic base.

As a result of carbonization and activation, the morphology of the material changed significantly: the dense structure of the original husk was transformed into a porous carbon-silica matrix. Pores of varying diameters appeared on the surface, indicating partial combustion of organic components and the removal of volatile substances. The formation of porosity is also associated with the destruction of cell walls and intercellular septa during high-temperature treatment. The following characteristic peaks are clearly defined in the spectrum: The D-peak is located in the region of approximately $\sim 1350\text{ cm}^{-1}$. This peak is associated with disturbances in the structure of graphite-like carbon and is caused by modes of hexagonal rings of carbon atoms with sp^2 hybridization. The presence of this peak indicates defects and grain boundaries in the material. The G-peak is observed in the region of approximately $\sim 1580\text{ cm}^{-1}$ and corresponds to the stretching vibrations of carbon atoms in flat sp^2 structures characteristic of graphite. This peak indicates the presence of ordered graphene-like regions in the material. The 2D-peak (second order of the D-peak) appears in the region of approximately $\sim 2700\text{ cm}^{-1}$. Its shape and intensity allow us to judge the number of graphene layers and the degree of graphitization (Figure 5).

The Raman spectrum of activated carbon obtained from walnut shells clearly displays characteristic D ($\sim 1350\text{ cm}^{-1}$), G ($\sim 1580\text{ cm}^{-1}$), and 2D ($\sim 2700\text{ cm}^{-1}$) bands, indicating the presence of carbon structures with varying degrees of order. Band D reflects the presence of defects and disordered regions in the carbon lattice, arising from the activation and partial amorphization of the material. Band G corresponds to vibrations of carbon atoms in graphite-like sp^2 -hybridized regions, characterizing the presence of ordered domains. Band 2D is associated with graphene-like structures and is used to estimate the number of layers and the degree of graphitization of the carbon. Thus, the set of observed peaks indicates that the obtained material is partially graphitized nanostructured carbon with a combination of ordered and defective regions.

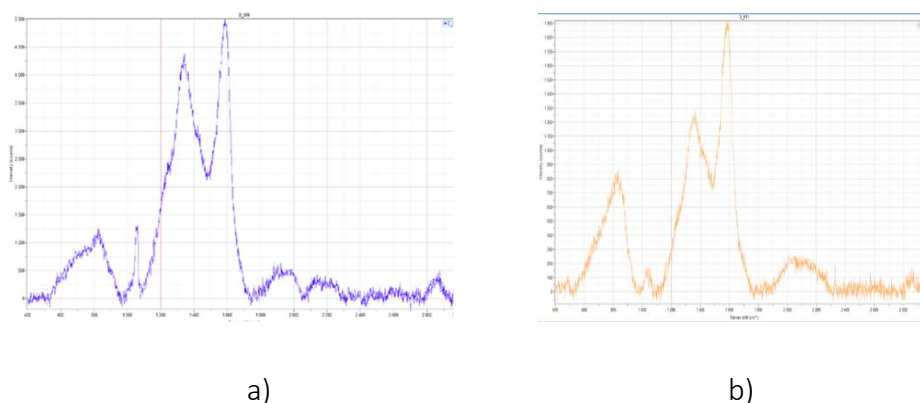


Figure 5 - Raman spectrum: a - Walnut-based AU, b - Walnut-based activated carbon (GO/KOH = 8:1)

For the walnut-based AC sample (GO/KOH = 8:1), peaks were recorded in the spectrum at $\sim 1350\text{ cm}^{-1}$ (D), $\sim 1585\text{ cm}^{-1}$ (G), and $\sim 2675\text{ cm}^{-1}$ (2D). The intense D peak reflects the high concentration of structural defects arising during aggressive alkaline activation. The G peak indicates the preservation of ordered sp^2 regions of the graphite type, and the broad and asymmetric 2D peak indicates the formation of multilayer nanographite-like structures. Thus, an increase in the amount of activator (KOH) promotes a deeper structural rearrangement of the carbon matrix, forming a defective but partially graphitized nanoporous structure with high surface activity. The adsorption characteristics of walnut-based activated carbon (900°C) are presented in Figure 6 and Table 6.

The BET surface area is $\sim 34.8\text{ m}^2/\text{g}$, indicating the development of a moderately porous structure. This is typical of mesoporous materials or partially activated carbons of medium activity. The total pore volume is $0.0453\text{ cm}^3/\text{g}$, also indicating a moderate level of porosity. Micropores are virtually absent, as evidenced by the negative t -Plot value for microporosity ($-0.004\text{ cm}^3/\text{g}$).

Consequently, the structure is predominantly mesoporous, with pores of 4–6 nm in size predominating.

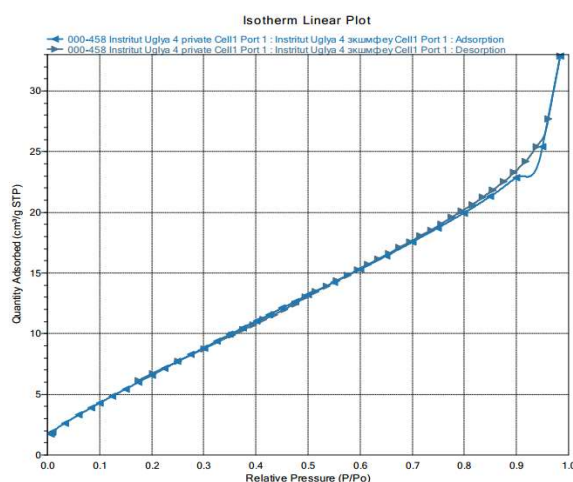


Figure 6 - BET surface area graph of walnut-based AC (900°C)

Table 6 - Adsorption characteristics of activated walnut-based AC, 900°C

No	Characteristics	Value
Surface area		
1	BET surface area	34,82 cm ³ /g
Pore volume		
2	Total pore volume at p/p0 = 0.99000	0,0453 cm ³ /g
3	Total adsorption pore volume of BJH	0,0439 cm ³ /g
Pore size		
4	Average pore diameter (4V/A)	5,21 nm
5	BJH Adsorption Average Pore Diameter	5,74 nm
6	The most common adsorption pore diameter according to BJH (dV/dD):	4,8 nm
7	Pore diameter of BJH desorption media	5,2 nm
8	Most common desorption pore diameter according to BJH (dV/dD)	4,9 nm
HK/SF micropore analysis (<2 nm)		
9	Micropore volume	0,0085 cm ³ /g
10	The most common pore diameter	1,20 nm
11	Average pore diameter	1,21 nm

The most common pore diameter according to BJH is approximately 5 nm, confirming the mesoporous nature of the material. The Horvath-Kawazoe (HK) method reveals the presence of a small number of narrow pores with a diameter of ~1.2 nm, but their contribution to the overall structure is insignificant. The material has an average specific surface area (~35 m²/g), a mesoporous structure with a pore diameter of ~5 nm, a low micropore volume, and good potential for adsorption of medium-sized molecules (e.g., dyes, organic substances, and gases).

The adsorption characteristics of walnut-based AC (GO/KOH = 8:1) are presented in Figure 7 and Table 7.

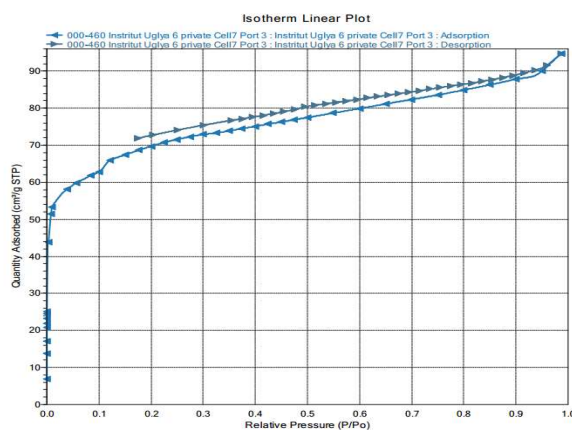


Figure 7 - BET surface area graph of walnut-based AU (GO/KOH = 8:1, 900°C)

The results demonstrate that the sample is a combination of pores: it has a significant total surface area (~248 m²/g) and a significant proportion of micropores (volume ≈0.0446 cm³/g), with the bulk of the volume and the modal portion of the distribution being mesopores with characteristic sizes of ~3–4 nm (according to BJH). This combination (micro + mesopores) ensures both high sorption capacity (micropores) and good mass transfer kinetics (mesopores).

The adsorption characteristics of the walnut-based adsorbent (GO/KOH = 8:1, 900 °C) indicate its high efficiency and potential for use in various adsorption processes. The results, presented in Table 42 and Figure 17, highlight the importance of selecting starting materials and activation conditions to obtain adsorbents with optimal characteristics.

Table 7 – Adsorption characteristics of activated charcoal based on activated walnut with KOH, GO/KOH=1:8900°C

No	Characteristics	Value
Surface area		
1	BET surface area	248,31 m ² /g
2	t-Plot Micropore area	154,16 m ² /g
3	t-Plot External surface area	94,14 m ² /g
Pore volume		
4	Total pore volume at p/p ₀ = 0,99000	0,14675 cm ³ /g
5	t-Plot Micropore volume	0,04465 cm ³ /g
6	Total volume of adsorption pores BJH	0,06745 cm ³ /g
7	BJH desorption, cumulative pore volume:	0,06483 cm ³ /g
Pore size		
8	Average pore diameter (4V/A)	2,36 nm
9	BJH Adsorption Average pore diameter	3,85 nm
10	The most common adsorption pore diameter is BJH (dV/dD):	3,5 nm
11	Pore diameter of desorption media BJH	3,6 nm
12	The most common desorption pore diameter is BJH (dV/dD)	3,6 nm
Micropore analysis HK/SF (<2 nm)		
12	Micropore volume	0,04465 cm ³ /g
14	The most common pore diameter	0,8 nm
15	Average pore diameter	0,7 nm

Table 7 presents the physicochemical characteristics of activated carbons (ACs) obtained from rice husks by thermochemical activation using various reagents: NaOH, KOH, and K₂CO₃.

Moisture content (%) indicates the moisture content of the activated carbon. Lower moisture values indicate a more efficient drying and activation process, which may positively impact the adsorption properties of the material. For example, activated rice husks with a RSH/NaOH ratio of 1/0.5 have the lowest moisture content (5.7039%), which may indicate more optimal activation conditions. Ash content indicates the content of inorganic residues in the activated carbon. High ash content can negatively impact adsorption properties, as inorganic components can occupy pores and reduce surface area. For example, activated rice husk with KOH at a ratio of 1/1 has an ash content of 54.0480%, which is the highest value among the presented samples, which may indicate the presence of a large amount of inorganic residues.

Bulk density (g/cm³) reflects the mass of activated carbon per unit volume and can influence its use in various processes. Generally, a higher bulk density indicates better compaction and stability of the material. The sample with a ratio of RSH/K₂CO₃ = 1/0.5 has the highest bulk density (0.255 g/cm³), which may be beneficial for some technological processes. The pH of activated carbon can affect its adsorption properties, particularly for ions and molecules in solution. A higher pH (e.g., 10.07 for RSH/NaOH = 1/0.5) may indicate higher alkalinity, which may be beneficial for the adsorption of certain contaminants. At the same time, a lower pH may be more suitable for other types of adsorption.

Testing a Biochar-Based Adsorbent for Wastewater Treatment

To evaluate the effectiveness of the synthesized activated carbon adsorbents in wastewater treatment, laboratory and field tests of their adsorption properties were conducted on real wastewater. Wastewater collected from the wastewater treatment plant of the Astana Su Arnasy State Enterprise (Astana) was used for testing. Sampling was performed in the distribution chamber before the preliminary mechanical treatment stage (Figure 8), allowing for an objective assessment of the effectiveness of the adsorption stage as part of the integrated treatment scheme. Based on the analysis results, purification rates were calculated for key indicators and compared with current wastewater quality standards.



Figure 8 – Samples of the original wastewater and after adsorption treatment with sorbents

After treatment with activated walnut shells and KOH (8:1) at 900°C, the water became lighter in color and significantly more transparent. Suspended solids were effectively precipitated, and color was virtually absent. This indicates the high efficiency of walnut shell activation with potassium hydroxide and the developed porous structure of the resulting adsorbent.

Biochemical oxygen demand (BOD) is a key indicator of wastewater contamination with organic matter. The lower the BOD value after treatment, the greater the effectiveness of the sorption material in removing organic contaminants susceptible to biochemical oxidation. The initial BOD concentration in the control wastewater sample was 200.0 mg/dm³. After adsorption treatment with various sorbents obtained, the following results were obtained: activated walnut with KOH (8:1, 900°C) – 83.0 mg/dm³ (58.5%) (showed a negative effect, increasing the BOD value, indicating low sorption activity for this indicator). Wastewater treatment using activated adsorbents. To evaluate the effectiveness of various adsorbents in wastewater treatment, suspended solids were determined. The control suspended solids concentration was 139 mg/dm³. After wastewater treatment with various adsorbents, a decrease in concentration was observed: activated walnut with KOH (8:1, 900°C) – 88.0 mg/dm³ (36.7%).

The initial COD concentration was 444 mg/dm³. After treatment, the following decrease was observed: activated walnut with KOH (8:1, 900 °C) - 169.0 mg/dm³ (61.9%). The initial sulfate value (mg/dm³) was 198.0 mg/dm³. After treatment: activated walnut with KOH (8:1, 900 °C) - 199.0 mg/dm³ (0%). The initial concentration of ammonium nitrogen (mg/dm³) in the wastewater was 46.38 mg/dm³. After treatment with various adsorbents, a decrease in concentration was observed: activated walnut with KOH (8:1, 900 °C) - 41.79 mg/dm³ (9.9%).

The initial concentration of iron (mg/dm³) in the wastewater was 2.35 mg/dm³. After treatment with various adsorbents, a decrease in iron content was observed: activated walnut with KOH (8:1, 900°C) - 1.62 mg/dm³ (31.1%). The control phosphate concentration (mg/dm³) in the wastewater was 13.05 mg/dm³. After treatment with various adsorbents, the following

decrease in concentration was observed: activated walnut with KOH (8:1, 900°C) - 13.28 mg/dm³ (unchanged). Initial surfactant value, mg/dm³ - 6.81 mg/dm³. After purification: activated walnut with KOH (8:1, 900°C) - 1.97 mg/dm³ (71.07%). In terms of petroleum product purification (mg/dm³), almost all adsorbents demonstrated the highest purification rates. The control sample contained 27.87 mg/dm³. After purification, activated walnuts with KOH (8:1, 900°C) contained 6.85 mg/dm³ (75.4%).

As a result of the research, a highly effective carbon adsorbent based on walnut shell biomass and rice husks was developed. The adsorbent was obtained by carbonization and thermochemical activation using potassium hydroxide (KOH). It was found that alkaline activation at 900°C and a KOH/KOH ratio of 8:1 promotes the formation of a developed micro- and mesoporous structure, as confirmed by SEM, TEM, BET, and Raman spectroscopy. The addition of KOH was shown to significantly increase the specific surface area (up to 248.31 m²/g), increase micropore volume, and reduce ash content, as well as increase the carbon content in the material (up to 79.1%). Gas chromatographic and thermogravimetric studies confirmed the active thermochemical processes and profound restructuring of the carbon matrix during activation.

Laboratory and production tests on actual wastewater from the Astana Su Arnasy State Enterprise demonstrated the high efficiency of the resulting adsorbent in removing organic and toxic pollutants. The following purification levels were achieved: COD – up to 61.9%, surfactants – 71.1%, petroleum products – 75.4%, suspended solids – 36.7%, and iron – 31.1%. The organoleptic properties of the water significantly improved, and turbidity and coloration decreased. Thus, using agro-industrial waste as a raw material for producing activated carbon adsorbents is an environmentally and economically viable approach. The resulting materials can be recommended for use in wastewater post-treatment technologies, as well as in water treatment and industrial filtration systems.

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STUDY OF THE COMPLEXATION ABILITY OF SILVER WITH BENZOIC ACID DERIVATIVES

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Keywords: *Silver ion, silver benzoate, ligand–metal interaction, σ -donor bond, π -acceptor bond*

Ключевые слова: *Ион серебра, бензоат серебра, взаимодействие лиганд-металл, σ -донорная связь, π -акцепторная связь*

The formation of complexes of transition metals with oxygen-donor ligands is one of the important directions of coordination chemistry. In this regard, the interaction of silver (I) ion (Ag^+) with organic ligands containing carboxyl groups, especially benzoic acid and its derivatives, is of great interest from a scientific and applied point of view. Benzoic acid derivatives have a carboxyl group attached to an aromatic ring, and both electron-donor and steric effects determine the nature of the metal-ligand interaction.

Among the transition metals, silver has unique chemical properties. It is widely used in the preparation of important compounds that are widely used as alternative energy sources by forming two-, three- and four-phase systems with silver chalcogenides [1-7]. One of the most important properties of silver is its ability to form complex compounds. This property is widely used in analytical chemistry, electrochemistry, photography and industry. Silver forms stable complexes mainly in the +1 oxidation state.

Silver benzoate and its derivatives are considered promising compounds in the preparation of antibacterial agents, catalytic systems and functional materials. The formation of silver complexes has a wide range of applications in titrimetric analyses, qualitative and quantitative analysis, electroanalytical methods, and the preparation of medical and antibacterial materials. [9.1 (2026): 9].

Ag^+ Since the ion is a soft Lewis acid, it forms stable complexes mainly with soft Lewis bases. This property is explained by the HSAB (Hard and Soft Acids and Bases) theory proposed by Ralph Pearson. The HSAB theory is a concept that explains which ions and molecules are more favorable for chemical reactions. It is characteristic for silver to form complexes with a linear or tetrahedral structure. The most common ones are complexes with a linear coordination number of 2 or tetrahedral coordination number of 4.

The complexation ability of silver with benzoic acid and its derivatives is one of the important areas of coordination chemistry. Various coordination modes of carboxylate ligands lead to the formation of complexes with silver ion, mainly with a polymeric structure. The electronic effect of substituents on the aromatic ring is one of the main factors determining the stability and physicochemical properties of the complexes. These complexes are of great scientific importance for both theoretical studies and applied fields.

Benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$) and its derivatives coordinate with silver ions mainly through the deprotonated carboxylate anion ($-\text{COO}^-$). These ligands are called O-donor ligands and bind to the metal ion in monodentate, bidentate or bridging topotypes. The +J, -J, +M, -M electronic effects, position and nature of the substituents ($-\text{NO}_2$, $-\text{CH}_3$, $-\text{OH}$, $-\text{Cl}$, $-\text{NH}_2$ etc.) on the aromatic ring have a significant impact on the stability and structure of the Ag complexes. [9.1 (2026): 9].

The Ag^+ ion is mainly stable in the +1 oxidation state, with low coordination numbers (2–4) prevailing. According to the HSAB theory, Ag^+ is a soft Lewis acid, but it can form moderately stable complexes with carboxylate ions. This is mainly explained by electrostatic effects and crystal structure factors.

Silver benzoate is usually obtained by the reaction of silver nitrate with a salt of benzoic acid, which has [9.1 (2026): 9].



Benzoic acid derivatives exhibit various types of coordination with the silver ion (Ag^+). In these complexes, the metal–ligand bond usually consists of two components.

1. σ -bond (sigma bond) – ligand \rightarrow metal
2. π -interaction (pi interaction) – metal \rightarrow ligand (or vice versa)

Together, these interactions determine the strength and nature of the metal–ligand bond.

A σ -donor ligand is a ligand that donates a lone pair of electrons to a central metal ion, forming a coordination (donor-acceptor) bond. A filled orbital of the ligand (e.g., a lone pair of electrons from an O, N, or S atom) is covered by an empty orbital of the metal ion, resulting in a σ -type bond. In other words, a σ -donor bond is the transfer of an electron pair from the ligand to the metal ion, **π -acceptor** bonding is characterized by the ligand accepting the d-electrons of the metal into an empty π^* orbital. Benzoic acid derivatives bind to silver mainly as σ -donors and weak (partial) π -acceptors.

In benzoic acid derivatives, the oxygen atoms of the carboxylate group act as σ -donors. A π -acceptor ligand is a ligand with an empty π^* (antibonding) orbital that can accept electron density from a metal ion. This process is called π -backbonding. The filled d-orbital of the metal donates an electron to the empty π^* orbital of the ligand, and electron transfer occurs in the metal \rightarrow ligand direction. Not all ligands are strong π -acceptors.

In a partial π -acceptor, the ligand is mainly a σ -donor, but can accept π -electron density from the metal ion, albeit weakly.

Benzoic acid derivatives have a π -electron system in the carboxylate group ($\text{C}=\text{O}$), which is conjugated with an aromatic ring. Therefore, they have a weak π -acceptor ability. However, this effect is much weaker than that of CO and CN^- , which is why the term “partial” is used.

In the monodentate coordination type, only one oxygen atom of the carboxylate group is bonded to the Ag^+ ion. In the bidentate (alloyed) coordination type, both oxygen atoms are bonded to the metal ion, but this is relatively rare for silver. In the bridging ($\mu\text{-COO}^-$) coordination type, the carboxylate group combines two or more Ag^+ ions and forms polymeric complexes. [9.1 (2026): 9].

Substituents located on the aromatic ring of benzoic acid affect the stability of the complexes. Electron-withdrawing groups ($-\text{NO}_2$, $-\text{Cl}$) reduce the donor capacity of the carboxylate oxygens, weakening the stability of the complex. Electron-donating groups ($-\text{CH}_3$, $-\text{OCH}_3$, $-\text{OH}$) increase the electron density and strengthen the metal-ligand bond.

These effects are observed in the infrared spectra by changing the frequencies of $\text{vas}(\text{COO}^-)$ and $\text{vs}(\text{COO}^-)$.

In the study of silver benzoate complexes, the carboxylate bonding type was determined by IR spectroscopy, ligand-metal interactions were evaluated by UV spectroscopy, polymer structure was determined by X-ray structural analysis, and thermal stability was determined by thermal analysis (TGA, DSC). The difference in IR spectra $\Delta\nu = \text{vas} - \text{vs}$ is the main indicator in determining the coordination mode. [9.1 (2026): 9].

Conclusion

The complexing ability of silver is one of the main aspects of its chemical properties. The fact that the Ag^+ ion is a soft Lewis acid, forms complexes with a low coordination number and linear structure, makes this metal play an important role in both theoretical and practical chemistry. Complexes of the Ag^+ ion are an integral part of modern analytical, industrial and technological processes.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ТЕХНОЛОГИЙ СИНТЕЗА ПОЛИОКСИХЛОРИДА АЛЮМИНИЯ: ОЦЕНКА ТЕХНОЛОГИЧЕСКОЙ ОСУЩЕСТВИМОСТИ И ЭКОНОМИЧЕСКОЙ ЭФФЕКТИВНОСТИ

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Современное промышленное развитие характеризуется возрастающей нагрузкой на окружающую среду, проявляющейся, с одной стороны, в накоплении значительных объемов техногенных отходов, а с другой – в загрязнении водных ресурсов. Алюминиевая промышленность генерирует большое количество вторичных шлаков, относящихся к опасным отходам, в то время как предприятия различных отраслей нуждаются в эффективных реагентах для очистки сложных сточных вод. Одним из таких реагентов является полиоксихлорид алюминия (ПОХА), отличающийся высокой коагуляционной активностью, работой в широком диапазоне pH и образованием меньшего объема осадка по сравнению с традиционными солями алюминия.

В настоящее время актуальным является поиск баланса между экономической эффективностью и качеством конечного продукта. Существуют два принципиальных подхода к производству ПОХА: традиционный, основанный на использовании высококачественного первичного сырья, и ресурсосберегающий, соответствующий принципам циркулярной экономики, предполагающий утилизацию алюминийсодержащих отходов. Однако в научно-технической литературе отсутствуют прямые сопоставительные данные, позволяющие объективно оценить, может ли продукт из вторичного сырья служить полноценной заменой промышленному стандарту. Целью данного исследования стало проведение комплексного сравнительного анализа двух технологий синтеза ПОХА – из вторичного алюминиевого шлака и первичного металлического алюминия – с оценкой их технологической осуществимости, качества продукции и потенциала для промышленного внедрения.

Методология и объекты исследования

Объектами исследования выступили вторичный алюминиевый шлак с предприятия по переработке лома и первичный алюминий марки А7. Методология включала параллельное проведение двух технологических процессов.

Для синтеза ПОХА-Ш был разработан многостадийный процесс, включающий: 1) механическую активацию шлака мокрым помолом; 2) водно-термическую промывку для гидролиза нитрида алюминия (AlN) и удаления водорастворимых солей; 3) кислотное выщелачивание подготовленного сырья соляной кислотой с оптимизацией параметров (концентрация HCl, соотношение жидкость:твердое, температура, время); 4) полимеризацию полученного алюмосодержащего раствора.

Технология получения ПОХА-П воспроизводила стандартный промышленный метод: прямое растворение стружки первичного алюминия в соляной кислоте с контролем температуры (70-80°C) до полного перехода металла в раствор.

Для сравнительной оценки применялся комплекс аналитических методов: сканирующая электронная микроскопия (СЭМ), рентгенофлуоресцентный (XRF) и рентгенофазовый (XRD) анализ, ИК-спектроскопия, определение стандартных физико-химических показателей (содержание Al_2O_3 , плотность, pH). Коагуляционная эффективность оценивалась методом джар-теста на модельной сточной воде с анализом мутности, содержания взвешенных веществ, химического потребления кислорода (ХПК) и цветности.

Анализ результатов и их обсуждение

1. Характеристика сырья и сложность предобработки. Исходный вторичный шлак представлял собой гетерогенный материал сложного элементного (Al, Cl, Si, Mg, Na, Ca) и фазового состава (Al, Al_2O_3 , AlN, NaCl, MgAl_2O_4 , CaF_2). Наличие реакционноспособного AlN и балластного NaCl обусловило необходимость обязательной стадии предварительной водной промывки. Механическая активация позволила увеличить удельную поверхность сырья и гомогенизировать его состав, что являлось критическим условием для последующего эффективного выщелачивания.
2. Оптимизация процесса и извлечение алюминия. Для стадии кислотного выщелачивания шлака были определены оптимальные параметры: концентрация HCl – 20%, соотношение Ж:Т – 4:1, температура – 80°C, время – 60 мин. Максимальная степень извлечения алюминия составила **61,2%***, что объясняется присутствием в шлаке химически стойких фаз (корунд, шпинель), нерастворимых в данных условиях. Процесс синтеза ПОХА-П не требовал оптимизации и характеризовался высокой воспроизводимостью и полнотой использования сырья.
3. Сравнительная характеристика продуктов. Физико-химический анализ выявил существенную разницу в качестве конечных продуктов (Таблица 1).

Таблица 1. Сравнительные показатели синтезированных коагулянтов

Показатель	ПОХА-Ш (из шлака)	ПОХА-П (из первичного Al)	Требования стандарта (СТ РК 3761-2022)
Содержание Al_2O_3 , %	12.6	17.5	17.0-22.0
Плотность, г/см ³	1.21	1.28	≥ 1.25
Внешний вид	Желтоватый, опалесцирующий	Бесцветный, прозрачный	Слабоокрашенный или бесцветный

Продукт ПОХА-П полностью соответствовал промышленному стандарту. ПОХА-Ш не соответствовал требованиям по основным показателям, а его ИК-спектры указывали на наличие примесей и менее однородную полимерную структуру.

4. Оценка коагуляционной эффективности. Испытания на модельной сточной воде подтвердили значительное преимущество стандартного продукта (Таблица 2). ПОХА-П обеспечил удаление взвешенных веществ на 99%, а ХПК и цветности – на 85% и 95% соответственно. ПОХА-Ш показал существенно более низкую эффективность: удаление взвешенных веществ – 70%, ХПК – 40%, с формированием рыхлых хлопьев и неполным осветлением воды.

Таблица 2. Результаты очистки модельной сточной воды

Параметр	Исходная вода	После ПОХА-Ш	После ПОХА-П
Мутность, NTU	150	52.5	3.0
Взвешенные вещества, мг/л	200	60	2
ХПК, мг/л	400	240	60

Проведенное исследование дает четкие, основанные на экспериментальных данных выводы для принятия управленческих и инвестиционных решений в химической промышленности и секторе водоочистки.

1. Технологическая зрелость и качество продукта. Технология синтеза ПОХА из первичного алюминия подтвердила статус отработанного промышленного стандарта, гарантирующего стабильное высокое качество коагулянта, соответствующего нормативным требованиям. Это надежное решение для производителей, ориентированных на рынок высокоэффективных реагентов для ответственных применений, включая очистку питьевой воды и сложных промышленных стоков.

2. Потенциал и барьеры ресурсосберегающей технологии. Технология получения ПОХА из вторичных алюминиевых шлаков доказала свою принципиальную техническую осуществимость и соответствует трендам циркулярной экономики. Ее ключевые потенциальные преимущества для бизнеса:

- Снижение себестоимости сырья за счет использования отходов.
- Повышение ресурсной эффективности и экологический эффект от утилизации опасных отходов, уменьшения объема захоронения.
- Формирование высокореакционноспособных поликатионов в продукте, что указывает на наличие коагуляционной активности.

Однако на текущем уровне проработки технология обладает критическими коммерческими барьерами:

- Низкое качество продукта: Полученный ПОХА-Ш не соответствует ключевым параметрам стандарта, что ограничивает его конкурентоспособность на основном рынке.
- Высокая капиталоемкость и сложность:** Процесс требует многостадийной предобработки и оптимизации, что увеличивает затраты на оборудование и эксплуатацию.
- Ограниченная эффективность: Коагуляционная способность продукта существенно уступает стандартному аналогу, сужая потенциальные области применения.

3. Стратегические ориентиры для коммерциализации. Для перевода технологии ПОХА-Ш из категории экспериментальной в коммерчески успешную необходимы:

- Дальнейшие НИОКР, сфокусированные на разработке эффективных и экономичных методов глубокой очистки и концентрирования промежуточных растворов для повышения содержания Al_2O_3 и удаления примесей.
- Поиск нишевых рынков сбыта, где требования к чистоте коагулянта ниже, но востребована его экономическая и экологическая составляющая (например, предварительная очистка некоторых типов промышленных стоков, применение в строительстве).
- Государственная поддержка в рамках программ по стимулированию переработки промышленных отходов и развитию «зеленых» технологий, которая может улучшить экономику проекта.

Таким образом, в краткосрочной и среднесрочной перспективе технология на основе первичного алюминия остается безальтернативной для производства высококачественного коагулянта. Технология на основе вторичного сырья представляет собой перспективное, но требующее серьезной дополнительной проработки направление для стратегических инвестиций в контексте долгосрочного перехода к циркулярной экономике и снижению экологического следа производств.

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РАЗРАБОТКА И ЭКСПЕРИМЕНТАЛЬНАЯ АПРОБАЦИЯ ГИДРОИМПУЛЬСНОЙ ТЕХНОЛОГИИ ОЧИСТКИ НЕРУДНЫХ СТРОИТЕЛЬНЫХ МАТЕРИАЛОВ

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В условиях интенсификации горнодобывающей и строительной отраслей, сопровождающейся ростом объемов добычи и переработки минерального сырья, особую значимость приобретает совершенствование технологий обогащения и очистки полезных ископаемых. Традиционные методы переработки минерального сырья характеризуются высокой энергоёмкостью, значительными потерями ценных компонентов, а также существенной экологической нагрузкой, связанной с образованием отходов и загрязнением окружающей среды.

Современные тенденции устойчивого развития, ужесточение экологических требований и необходимость повышения ресурсной эффективности обуславливают спрос на инновационные технологические решения, обеспечивающие повышение качества переработки минерального сырья при одновременном снижении негативного воздействия на окружающую среду. В этом контексте особый интерес представляют технологии гидроимпульсного обогащения и очистки, основанные на использовании импульсных гидродинамических воздействий, позволяющих повысить селективность разделения минеральных компонентов и эффективность очистки сырья.

Развитие и локализация производства линий гидроимпульсного обогащения и очистки полезных ископаемых являются важным направлением технологической модернизации горнодобывающей и строительной отраслей, способствующим снижению зависимости от импортного оборудования, повышению конкурентоспособности отечественных предприятий и формированию инновационного промышленного потенциала. В связи с этим исследование, направленное на обоснование и разработку производственных решений в области создания линий гидроимпульсного обогащения и очистки полезных ископаемых, является актуальным с научной и практической точек зрения.

Методологическая основа исследования базируется на системном и междисциплинарном подходах, объединяющих методы технических, экономических и экологических исследований. В процессе работы применяются как общенаучные, так и специальные методы познания.

В рамках теоретического этапа исследования используются методы анализа и синтеза, индукции и дедукции, а также сравнительный анализ отечественного и зарубежного опыта проектирования и эксплуатации технологий гидроимпульсного обогащения и очистки полезных ископаемых. Это позволяет выявить ключевые технологические особенности, преимущества и ограничения рассматриваемых решений.

Эмпирическая часть исследования основана на использовании методов технико-экономического анализа, моделирования производственных процессов и оценки эффективности функционирования технологических линий. Применяются методы

расчетного анализа параметров гидроимпульсного воздействия, а также оценка показателей производительности, энергоёмкости и качества обогащения минерального сырья.

Для обоснования практической целесообразности внедрения разрабатываемых линий используются методы инвестиционного анализа, включая расчет показателей экономической эффективности, а также методы экологической оценки, направленные на определение уровня снижения отходов и воздействия на окружающую среду. Комплексное применение указанных методов обеспечивает достоверность и обоснованность полученных результатов и выводов исследования.

В рамках выполнения научно-исследовательской работы разработан электрогидравлический метод очистки щебня и минерального отсева от глинистых и илистых примесей, а также создана и апробирована экспериментальная лабораторная установка. Конструкция установки включает генератор импульсных напряжений (повышающий трансформатор, высоковольтный выпрямитель и накопительный конденсатор), рабочий модуль с электродной системой и систему водоподачи.

По результатам НИР получены следующие основные результаты: разработан электрогидравлический метод очистки нерудных строительных материалов от глинистых и пылеватых примесей; собрана и экспериментально испытана лабораторная установка, реализующая электрогидроимпульсный принцип очистки; экспериментально подтверждено, что использование электрогидравлического аппарата обеспечивает повышение степени очистки строительных материалов на 10–20 % по сравнению с традиционными технологиями.

В ходе предварительных исследований проведены сравнительные лабораторные испытания технологии гидроимпульсного разряда на образцах щебня фракций 0–5, 5–20 и 20–40 мм. Установлено, что после обработки содержание глинистых и пылевидных примесей снижается до 0,5 %, что соответствует требованиям ГОСТ 8267–93. Для сопоставления, при применении вибрационных грохотов остаточное содержание примесей составляет 8–10 %, а использование гидромеханических методов очистки требует предварительного измельчения материала, что приводит к снижению выхода кондиционного продукта.

Эффективность технологии дополнительно подтверждена оптимизацией режимных параметров процесса. Увеличение ёмкости накопительного конденсатора до 0,5 мкФ и расширение межэлектродного зазора с 6 до 12 мм позволили повысить частоту разрядов с 60 до 90 импульсов в минуту, сократить продолжительность очистки с 2–2,2 до 1–1,8 мин и увеличить степень отделения аморфных включений.

В целом применение гидроимпульсной технологии обеспечивает повышение качества очистки в 2–3 раза без нарушения кристаллической структуры обрабатываемого материала, что принципиально отличает данный метод от механических и гидромеханических способов переработки. Впервые реализован способ очистки и обогащения нерудных материалов на основе управляемых гидроимпульсных разрядов в водной среде, обеспечивающий селективное удаление аморфных примесей за счёт различий в модулях упругости компонентов. Формируемые разрядом локальные ударные волны с частотой до 90 Гц инициируют отслаивание примесей без механического истирания, что снижает износ оборудования, уменьшает энергопотребление и повышает качество конечного продукта.

Следует отметить, что в мировой практике представлены многочисленные исследования, посвящённые импульсным методам воздействия на минеральное сырьё. Так, в работах Adamyan E.V., Ananyeva A.V. и соавторов изучена технология магнитно-импульсной обработки рудного сырья перед флотацией. Показано, что магнитно-импульсное

воздействие способствует формированию дислокаций на границах минералов, облегчая их разделение и повышая степень высвобождения полезных компонентов, что приводит к увеличению извлечения никеля и меди без роста энергозатрат. В промышленном тестировании зафиксировано повышение извлечения никеля на 0,9 %, селективное разрушение межзерновых связей между пустой породой и сульфидными минералами без нарушения их кристаллической структуры, а также высокая энергоэффективность технологии (не более 0,2 кВт·ч/м³ руды).

В промышленной практике также применяется ультразвуковая обработка минеральных материалов; однако использование ультразвуковой кавитации сопряжено с высокой технологической сложностью, необходимостью дополнительного охлаждения оборудования и транспортировки обрабатываемого материала в рабочую зону, что приводит к увеличению капитальных и эксплуатационных затрат, а также энергопотребления.

При переходе от лабораторных условий к промышленной реализации гидроимпульсной технологии требуется адаптация параметров импульсного воздействия, включая энергию, частоту и индуктивность разрядной системы.

Разработанный способ очистки строительного щебня и отсева от глинистых и илистых примесей обладает рядом преимуществ по сравнению с зарубежными аналогами: сниженное энергопотребление, обеспечивающее повышение экономической эффективности производства; уменьшенный износ оборудования и его узлов; отсутствие необходимости использования химических реагентов, что минимизирует негативное воздействие на окружающую среду.

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Historical Sciences

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THE RICH HISTORICAL AND CULTURAL HERITAGE OF CAUCASIAN ALBANIA

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Xülasə

Azərbaycan tarixində elə mərhələlər vardır ki, həmin dövrü dərinlən araşdırmağa ehtiyac var.

Cənubi Qafqazın qədim dövlətlərindən biri olan Qafqaz Albaniyası Azərbaycanın qədim və erkən orta əsrlər tarixində əsas yer tutur. Məhz buna görə də Qafqaz Albaniyasının tarixinin və mədəniyyətinin öyrənilməsi problemi Azərbaycan tarixşünaslığında mühüm məsələlərdən biridir və tədqiqatçıların diqqət mərkəzindədir.

Şimali Azərbaycanın tarixi keçmişinin uzun bir dövrü Qafqaz Albaniyasının adı ilə bağlıdır. Buna görə də, Qafqaz Albaniyası tarixinin öyrənilməsi Azərbaycan üçün həmişə aktualdır. Bu istiqamətdə aparılan tədqiqatlar keçmişimizlə bağlı problemlərə xeyli işıq salıb.

Azərbaycan tarixində xüsusi iz qoyan və bizi tarixi keçmişimizə qaytaran kifayət qədər səbəb və hadisələr var. Müasir Azərbaycan tarixşünaslığında Qafqaz Albaniyasının öyrənilməsi sahəsində yeniliklər mövcuddur.

Açar sözlər: *Toponim, etnos, arxeoloji materiallar, tarixi mənbələr.*

Abstract

There are periods in the history of Azerbaijan, about which there is a need to write extensively and express an opinion.

Caucasian Albania, one of the ancient states of the South Caucasus, occupies a key place in the ancient and early medieval history of Azerbaijan. That is why the problem of studying the history and culture of Caucasian Albania is one of the important issues in Azerbaijani historiography and is in the focus of researchers' attention.

A long period of the historical past of Northern Azerbaijan is associated with the name of Caucasian Albania. Therefore, the study of the history of Caucasian Albania is always relevant for Azerbaijan. Research conducted in this direction has shed considerable light on the problems related to our past.

There are enough reasons and events that leave a special mark on the history of Azerbaijan and bring us back to our historical past. There are innovations in the field of studying Caucasian Albania in modern Azerbaijani historiography.

Keywords: *Toponym, ethnos, archaeological materials, historical sources.*

Резюме

В истории Азербайджана есть периоды, о которых необходимо подробно писать и выражать своё мнение.

Кавказская Албания, одно из древних государств Южного Кавказа, занимает ключевое место в древней и раннесредневековой истории Азербайджана. Именно поэтому проблема изучения истории и культуры Кавказской Албании является одним из

важных вопросов азербайджанской историографии и находится в центре внимания исследователей.

Долгий период исторического прошлого Северного Азербайджана связан с названием Кавказской Албании. Поэтому изучение истории Кавказской Албании всегда актуально для Азербайджана. Исследования, проводимые в этом направлении, значительно пролили свет на проблемы, связанные с нашим прошлым.

Существует достаточно причин и событий, которые оставляют особый след в истории Азербайджана и возвращают нас к нашему историческому прошлому. В современной азербайджанской историографии наблюдаются нововведения в области изучения Кавказской Албании.

Ключевые слова: *топоним, этнос, археологические материалы, исторические источники.*

Introduction

Over the centuries, several states have emerged in both the north and south of Azerbaijan, one of which is the state of Albania, which was formed on the territory of Azerbaijan in ancient times. Caucasian Albania played an important role in the political, cultural and religious history of the region.

To determine the place of Albania, which is considered one of the first states of the South Caucasus, in the history of Azerbaijan, it is enough to look at the geography covered by this state.

Caucasian Albania was a state distinguished by its own ethnic and religious diversity, but which united this diversity around the single ethnocultural space of the Albanian tribal union. In this regard, the historical sources of the multiculturalism policy and the roots of the principles of tolerance in the modern Republic of Azerbaijan benefit from the ancient traditions and ethnic-spiritual values of Caucasian Albania.

It is clear from early medieval written sources that the territory of Caucasian Albania extended to the confluence of the Araz and Kura rivers in the south, including Mil, Mughan plains, Paytakaran, and the Caspian Sea in the east. According to Musa Kalankatli, Albania stretched to the foothills of the Greater Caucasus Mountains in the north.

Caucasian Albania was a state distinguished by its unique ethnic and religious diversity, but uniting this diversity around the single ethnocultural space of the Albanian tribal union. In this regard, the historical sources of the multiculturalism policy and the roots of the principles of tolerance in the modern Republic of Azerbaijan benefit from the ancient traditions and ethnic-spiritual values of Caucasian Albania.

G. Geybullayev's research has its place in the ethnic study of the tribes included in the Albanian tribal union.

The ancient author who recorded the most extensive information about the Albanian state is Strabo. Strabo, in addition to his own research, gave an explanatory description of Albania, referring to works written before his time (the reports of Heraclid (323 BC) and Patroclus (283 BC), the works of Eratosthenes, Polybius and others).

According to ancient authors, there were more than 30 cities and other settlements in the territory of Caucasian Albania. Claudius Ptolemy, who lived in the 2nd century, mentions 29 cities and large settlements in the country. Ptolemy calls the settlements cities and villages. Among them were Teleba, Gelda, Albana and Gaytara, located on the coast of the Caspian Sea.

The work of Appian, who lived in the 2nd century, also contains information about the Albanians. This author, who was a contemporary of the Roman emperors Hadrian and Antoninus Pius and held an important position in the Roman court, witnessed important political events and recorded what he saw and heard. [1]

The issue of the borders of Albania in ancient times is also reflected in medieval sources. In this sense, it is necessary to first mention the work of M. Kalankatli "History of Albania".

It is impossible to study history in full detail based on written sources alone. The incompleteness and considerable contradictions of the historiography of Azerbaijan in the 19th and first half of the 20th centuries are largely due to the fact that the existing material and cultural monuments have not yet been sufficiently studied archaeologically.

Starting from the 1950s, the history of Albania has been intensively studied by Azerbaijani Albanian scholars, both from an archaeological and source-based perspective. We encounter particularly extensive research in the studies of Z.M. Bunyadov, I.H. Aliyev, M.Kh. Sharifli, Z.I. Yampolsky, G.A. Geybullayev, T.M. Mammadov, S.M. Ghaziyev and others.

Main part

The meager information in the sources about the emergence of the state as a social institution among the tribes living in the provinces of Northern Azerbaijan in ancient times allows us to assume that the state already existed in Albania at the end of the 4th century BC. Archaeological materials strengthen this assumption by showing that property inequality and class division deepened in Albania in the middle of the 1st millennium BC. Class division, as is known, is a necessary prerequisite for the emergence of a state institution.

The name of the country Albania comes from the name of the main ethnos living in the territory - the Albanian people of Turkic origin.

Recent information suggests that the toponym "Albania" is associated with the name of the Albanian ethnos that lived here.

According to the early medieval period, the territory of Albania was divided into provinces. The provinces of Albania included Kabalaka, Lpina, Kambisena, Sheki, Chola, Caspiana, Uti (the territory of Uti is mentioned as a province in some sources), Girdiman, Sakasena, Arsak, Syunik and Adjari.

Caucasian Albania, in modern terminology, was a multicultural state, distinguished by its unique ethnic and religious diversity, but uniting this diversity around the single ethnocultural space of the Albanian tribal union. In this regard, the historical sources of the policy of multiculturalism and the roots of the principles of tolerance in the modern Republic of Azerbaijan also benefit from the ancient traditions and ethical and moral values of Caucasian Albania.

The initial information about the tribes that migrated to Albania belongs to Herodotus, Strabo, and Hecataeus of Miletus. Along with the Albanian clans, the Caspians, Sakas, and other tribes lived here.

Ancient Albania is known for its diverse ethnic composition and dense population. According to Strabo, 26 Albanian tribes (tribes speaking 26 languages (dialects)) settled here. He wrote in his work that these tribes had difficulty communicating with each other.

In Albania, tribes belonging to various language families lived - tribes belonging to the eastern or Dagestan group of the Caucasian language family, the Turkic language family and the Iranian group of the Indo-European language family.

The languages of the Albanian tribes known in historical sources as the Lpi, Jilv, Leg and others can be attributed to the Dagestan group of the Caucasian language family.

There is information about the creation of the Albanian alphabet on the basis of the Gargar language. The Gargars settled along the Gargar River in Albania. Strabo reports that the Hilli (Hells) and Lihs (Lehs) lived here.

The population living in the territory of Caucasian Albania in the early Middle Ages can be divided into four main groups and summarized as follows:

1. Local (autochthonous) Caucasian origin: Lpins, Legs, Jilbs (Silvs), Tavasaps, etc.
2. Local (autochthonous) Turkic origin: Albanians, Utis, Gargars, Kaspis, Savdeys, Iymaks, etc.
3. In the 8th – 7th centuries BC, people of Turkic origin came: Maskuts, Saks, Kangars, Chols, Sabirs, Huns, Khazars, etc.
4. Iranian origin: Gauls, Persians, Arabs, etc. tribes. [4]

At the beginning of the 5th century, the Albanian alphabet was invented in Albania and began to be used in writing. This is considered a new form of the Albanian alphabet used at the beginning of the century and its use in official writings. The fact that objects with Albanian inscriptions were found in many monuments of the Karabakh region, as well as in Mingachevir, not far away, is a solid indication of the peculiarity of the writing culture. [3, p. 20]

There is information that the Albanians trace their roots to Alpoksa, the son of Targitay, the ancestor of the Scythians. The component “al” in the word “Alban” means “to obtain, to conquer”.

The ancient Greek geographer Strabo wrote that the Albanian lands were fertile, did not require much care from humans, sometimes yielded abundant crops without plowing or sowing, and that the land planted once sometimes yielded two or three crops. [2]

Strabo wrote about a number of characteristics of the Albanians. According to the author, the Albanians are tall and handsome. As for their characteristics, they are open-hearted, respectful people. They consider it one of the most negative characteristics to grieve or remember a deceased person. They bury all their property and belongings with the deceased. Therefore, they die from their ancestral property and live in poverty.

The Albanians worshiped the gods Helios (Sun), Zeus (Sky), and Selena (Moon). A temple dedicated to the moon god was located near Iberia. The existence of this temple showed that the worship of Selena was superior.

The Book of Dede Gorgud discusses the Albanians as one of the Turkic peoples, and one of the main characters of the work, Kazan Khan, is commemorated as the leader of the Alpans, that is, the Albanians. [5]

In the 80s-90s of the 20th century, the author of a number of research works on the early medieval period of the Caucasus, the Russian scientist A.P. Novoseltsev, showed that Christianity first spread in the Caucasus in the Arsak and Uti provinces of Albania. The Azerbaijani scientist F.C. Mammadova, who devoted a special study to the spread of Christianity in Albania, also noted that the first official adoption of the new religion in this country occurred immediately after the Edict of Milan, in 313, while other researchers noted that it occurred in the 30s of the 4th century or in the early period of the reign of ruler Urnair.

The Islamic religion was adopted by the main part of the ethnically rich population of Caucasian Albania and by the 12th century had already laid the foundation for the process of ethno-linguistic and cultural-ideological unification of Caucasian-speaking Albanians, Turkic-speaking and Iranian-speaking ethnic groups into a single Azerbaijani people, thereby creating a rich Muslim ethno-cultural heritage.

Conclusion

The history of Caucasian Albania is an important stage in the centuries-old statehood of Azerbaijan. At different periods of its existence, this country, along with the territory of the modern Republic of Azerbaijan, included the Zangezur region, the Goycha Lake basin, the Ganikh (Alazan) and Gabyrri (Iori) river basins, and part of southern Dagestan, including the city of Derbent.

The Albanian state was an early slave state with communal relations. The monuments of material culture of the Albanian period, certain elements of imagery on them, including decorative compositions, clearly embody the historical stages of development of the Turkic ethnoculture and its artistic way of thinking. Despite being exposed to different religious and ideological influences at different times, this culture was able to preserve its ethnocultural identity.

As can be seen from historical sources, Caucasian Albania played an important role in the development of the ancient history and culture of Azerbaijan, and in this regard, a deeper study and study of its history is important.

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Culturology

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ҚАЗАҚ МӘДЕНИЕТІНДЕГІ БАЛА ТӘРБИЕСІНІҢ ӨЗЕКТІ МӘСЕЛЕЛЕРІ

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Аннотация. Бұл мақалада қазақ мәдениетіндегі бала тәрбиесінің дәстүрлі жүйесі мен қазіргі кезеңдегі өзекті мәселелері философиялық-әлеуметтік тұрғыда талданады. Қазақ халқының бала тәрбиесіне қатысты көзқарастары ұлттық құндылықтар, салт-дәстүрлер және халықтық педагогика негізінде қарастырылады. Зерттеуде жаһандану, урбанизация және цифрлық технологиялардың ұлттық тәрбие жүйесіне әсері анықталып, отбасы институтының әлсіреуі мен ұрпақтар сабақтастығының үзілуі негізгі проблема ретінде айқындалады. Мақалада ұлттық тәрбиені заманауи білім беру жүйесімен үйлестіру жолдары ұсынылады.

Аннотация. В статье рассматриваются традиционная система воспитания детей в казахской культуре и ее актуальные проблемы в современных условиях. Анализируются национальные ценности, обычаи и элементы народной педагогики как основа формирования личности. Выявляется влияние глобализации, урбанизации и цифровых технологий на ослабление института семьи и преемственности поколений. Предлагаются пути интеграции традиционного воспитания с современной образовательной системой.

Abstract. The article examines the traditional system of child upbringing in Kazakh culture and its current challenges from a philosophical perspective. National values, customs, and elements of folk pedagogy are analyzed as the basis of personality formation. The impact of globalization, urbanization, and digital technologies on the weakening of family institutions and intergenerational continuity is identified. Ways of integrating traditional upbringing with the modern educational system are proposed.

Түйін сөздер: қазақ мәдениеті, бала тәрбиесі, ұлттық құндылықтар, халықтық педагогика, рухани тәрбие, философия.

Ключевые слова: казахская культура, воспитание детей, национальные ценности, народная педагогика, духовное воспитание, философия.

Keywords: Kazakh culture, child upbringing, national values, folk pedagogy, spiritual education, philosophy.

Бүгінде кез келген атананы алаңдататын сұрақтың бірі ол бала тәрбиесі. Себебі балаларды тәрбиелеу оңай дүние емес. Дегенмен, бұл ата-анасын және айналасындағыларды құрметтейтін толыққанды және өзін-өзі қамтамасыз ететін тұлғаны тәрбиелеу керек. Бұрын баланы тәрбиелеудің қазақ дәстүрі қандай болды? Несімен ерекшеленді?

Қазақ отбасындағы бала тәрбиесі – ғасырлар бойы қалыптасқан ұлттық құндылықтарға, дәстүрлерге және салт-саналарға негізделген ерекше жүйе. Қазақ халқы

балаға ерекше мән беріп, оны ұрпақтың жалғасы, отбасының тірегі, елдің болашағы деп санаған. Бала тәрбиесі отбасының ғана емес, бүкіл қауымның, ауылдың, тіпті рудың міндеті болып есептелген.

Қазақ отбасындағы бала тәрбиесінің негізгі ерекшеліктері бар екенін атап айтқан жөн. Ең бірінші Әкеге тән тәрбие: Әке балаға еңбекке, табандылыққа, батырлыққа, еліне қызмет етуге және жауапкершілікке үйреткен. Әке ұл баланың тұлға ретінде қалыптасуына ерекше назар аударған.

Екінші Анаға тән тәрбие: Ана мейірімділік пен сүйіспеншіліктің бастауы ретінде қыз баланы ұқыптылыққа, ізеттілікке, инабаттылыққа баулыған. Сонымен қатар, ана балаға ұлттық дәстүрлер мен отбасылық құндылықтарды үйретуде үлкен рөл атқарған.

Әже мен атаның рөлі: Қазақ отбасында әже мен атаның тәрбиелік маңызы зор болған. Олар балаларға ертегі айтып, мақал-мәтелдер арқылы өмірдің мәнін ұғындырған. Аталар батырлар жырын оқып, ұлттық рухты оятса, әжелер отбасы жылуын сақтаған.

Балаға берілетін рухани тәрбие. Ұлттық сана қалыптастыру: Баланы туған жерге, елге, тіліне, мәдениетіне және дініне құрметпен қарауға баулыған.

Қазақтар балаға өмірдің даналығын үйрету үшін мақал-мәтелдерді жиі қолданған: “Ұяда не көрсең, ұшқанда соны ілерсің”, “Атадан жақсы ұл туса, есіктегі басын төрге сүйрейді.”

Ерте жастан жауапкершілікке үйрету арқылы балаға жасына сай міндеттер жүктеп, жауапкершілікті сезінуді үйреткен.

Қазақ халқы баланы еңбекке ерте жастан баулыған. Ұл балалар мал бағу, егін егу сияқты шаруашылық жұмыстарға қатысса, қыз балалар үй шаруасымен айналысып, кесте тігіп, қолөнер үйренген. Бала еңбекті үлкендерден үйреніп, өз отбасына пайдалы болуды мақсат еткен. Ұл балалар атқа мініп, еркіндік пен батылдықты меңгерсе, қыз балалар үйдің жылуын сақтауды үйренген.

Дәстүрлер арқылы тәрбие. Шілдехана мен тұсаукесер: Бала дүниеге келгеннен бастап, қазақтар оны ұлттық дәстүрлермен өсірген.

Бесікке салу: Бесікке салу рәсімі арқылы сәбиді тәрбиелеудің алғашқы қадамы жасалса, тұсаукесер арқылы оның өміріне сәттілік пен жол ашу тілеген.

Сүндет той мен ашамайға мінгізу: Бұл дәстүрлер баланың қоғамдағы жаңа мәртебеге ие болуын көрсетіп, оның рухани және физикалық қалыптасуына ықпал еткен.

Әдеп пен инабатқа баулу. Баланы үлкенге құрмет көрсетуге, кішіге қамқор болуға тәрбиелеген. Қазақ отбасында балаға үлкендердің батасын алу маңызды саналған. Қыз балаға: “Қызға қырық үйден тыю” деген тәрбие беріліп, оның ар-намысын қорғау міндет болған.

Бала тәрбиесіндегі жауапкершілік. Қазақ халқында: “Балаңды – өз тәрбиеңмен тәрбиелеме, ұлтыңның тәрбиесімен тәрбиеле” деген сөз бар. Бұл ұлттың тәрбиесі мен құндылықтары әр бала үшін маңызды екенін көрсетеді. Бала тәрбиесінде әке мен ана, ата мен әже ғана емес, ауыл-аймақтың барлық үлкендері атсалысқан.

Қазіргі қазақ отбасындағы бала тәрбиесі. Қазіргі заманда қазақ отбасындағы тәрбиеде ұлттық дәстүр мен заманауи әдістер үйлесіп келеді.

Ұлттық құндылықтарға негізделген тәрбиемен қатар, баланы ғылыми, техникалық, шығармашылық тұрғыдан дамытуға көңіл бөлінуде.

Бала тәрбиесі тек отбасымен шектелмей, мектеп, қоғам, технологияның ықпалымен де жүзеге асып жатыр.

Қазақ отбасындағы бала тәрбиесі – ұрпақтан-ұрпаққа жалғасып келе жатқан рухани және мәдени мұра, оның негізгі мақсаты – елін сүйетін, ұлттық құндылықтарды бағалайтын саналы ұрпақ тәрбиелеу.

Қазақстандағы отбасылық дәстүрлер өз ұрпақтарын атау тұрғысынан, адамның жасына қарай мәртебесінде, сондай-ақ балаларды тәрбиелеу қағидаттарында көптеген ерекше ерекшеліктерге ие. Отбасылық қатынастар арнайы иерархияға негізделді және туыстық қатынастарға, белгілі бір тұқымға немесе руға жататындығына көп көңіл бөлінді. Бала тәрбиесі және баланың өсуіне байланысты әртүрлі рәсімдер діни сипатта болды, мұнда мұсылман және көшпелі дәстүрлердің симбиозы сезіледі.

Бірінші кезекте туыстық байланыстар институтын қалыптастырған "жеті ата" қағидатын (қазақ тілінен аударғанда "жеті әке") атап өткен жөн. Негізгі элемент-отбасының немересі ұлының баласы болды және ол "немере" деп аталды, ал қызының баласы "жиен" деп аталды, ол "жиен" деп аударылады және бұл ұрпақ енді осы тұқымға жататындығын талап ете алмады. Осылайша, тек ер адамдар тұқым қуалаушылар болды. Немересінен туған бала "шөбере", яғни "шөбере" деп аталды. Және т. б.: "шөберенің" ұлы "кішкентай" дегенді білдіретін "сыбыр" болды; оның ұлы "немен", яғни "түсініксіз", ал ұрпағы жетінші ұрпақта "туажат" деп аталды, бұл "бөтен болу үшін туылған" дегенді білдіреді. "Туажаттың" ұрпағы "жүрежат" деп аталды және басқа түрдің өкілі болып саналды. Осылайша, қазақтар өздерінің асыл тұқымын жетінші ұрпаққа дейін жүргізді және бұл адамдардың ата-бабаларын есте сақтау және құрметтеу үшін, ал практикалық жағынан жақын туыстарының арасында неке болмау үшін жасалды.

Қазақтардың отбасылық дәстүрлері ұлдарды тәрбиелеудің әртүрлі принциптерін де қамтыды: үлкен ұлы атасы мен әжесіне жіберілді, ортаншы ұлы жауынгер болуға дайындалды, ал кіші ұлы өздеріне қалдырылды және ол ата-анасына көмектесуі керек еді. Бала туылғаннан бастап көптеген рәсімдерден өтті, олардың кейбіреулері оған тәуелсіз және тәжірибелі адам болуға көмектесті.

Сондай-ақ, қазақ халқының өз өмірін "мүшел" деп аталатын 12 жылдық циклге бөлу дәстүрі бар және олар өмірдің бірінші жылынан кейін есептеле бастайды. Бірінші «мүшел» балалық шақты білдірді және 13 жасында аяқталды. Екінші "мүшель" өсуді білдірді, осы кезеңде жігіттер мен қыздар отбасын құруға, өз кәсібін табуға, үй шаруашылығын жүргізуге үйренуге мәжбүр болды. 25 жастан кейін, үшінші "мүшелде" ересек өмір басталды, адамдар қазірдің өзінде өмірлік тәжірибеге ие және барлық мәселелерді өз бетінше шеше алады. Төртінші "мүшел" 37 жасында басталды және даналықтың басталуын білдірді, мысалы, осы жастан бастап ер адамдар ақсақалдар деп аталуы мүмкін, бірақ олардың немерелері болған жағдайда. Бесінші «шыбын» белгілі бір мағынаға ие емес, бірақ бұл өмірдегі жетістіктердің көрсеткіші, сонымен қатар кәрілікке көшуді білдіреді. Алтыншы "шыбын" 61 жастан басталады және кәрілікті білдіреді. "Шыбынға" және адамның отбасылық жағдайына байланысты басқалардың оған деген көзқарасы тәуелді болды.

Қазақтар үшін отбасы-ең қасиетті. Қазақ отбасында бала тәрбиесі басты мәселелердің бірі болып саналады. Отбасындағы тәрбиенің барлық әдет-ғұрыптары мен дәстүрлері ұрпақтан-ұрпаққа беріліп отырды. Бұл ата-ананың негізгі тірегі және негізгі көзі болып табылатын отбасы. Біздің ата-бабаларымыз ешқашан байлық таппаған, өйткені олар көшпелі өмір салтын ұстанған. Олар өз ұрпақтарының рухани тәрбиесіне үлкен мән берді. Бала өмірінің алғашқы күндерінен бастап отбасында тәрбие сабақтарын алады. Қазақтың "ұяда не көресің, содан кейін ұшып бара жатасың" деген сөзі бар. Бұл жай сөз емес, бұл сөздердің мағынасы тереңде жатыр. Қазақ отбасында ұрпақтан-ұрпаққа берілетін ұлттық дәстүрлер мен жоғары мұраттар дәл отбасында қалыптасады. Адамдар арасындағы өзара түсіністікке әкелетін басқаларға деген сүйіспеншілік пен құрмет дәстүрлері тек сау отбасында қалыптасады. Бала кезінен бастап үлкендерге құрмет көрсетілді, қарым-қатынас бала кезінен басталады, кішілерге қамқорлық әрқашан қорқыныштың міндеті болды. "Бірінші арба қайда, соңғы арба да қайда барады", бұл сөздер үлкен ағалары мен әпкелерін мысалға келтірген кезде қазақ отбасыларында жиі айтылатын.

Көшпелі халықтар ұлдарын тәрбиелеуге қатаң қарады. Ұлы тек ұрпақтың ғана емес, сонымен бірге отбасының, туыстарының алғашқы тірегі болды. Барлық жауапкершілік үлкен ағалардың мойнына жүктелді, кішілері ата-аналарының қасында болды. Ал бүгін біз шынымен не көріп отырмыз?

Қазақ отбасыларындағы қыздарға деген көзқарас ерекше болды. Күнделікті өмір арқылы қыздарға тәрбие берілді. Қазақ халқының өмірі мен тұрмысында әйел отбасы шаруашылығының басты байлығы болып табылады. Ислам тараған басқа түркі халықтарымен салыстырғанда, қазақтар арасында қыздар әлдеқайда еркін және үлкен құқықтар мен құрметке ие болды. Отбасында керемет тәрбие алған қыз күйеуінің отбасында әдемі қалыңдық, қамқор әйел және балаларға жақсы ана болды. "Басқа біреудің отбасына қосыла отырып, сіздің туысқаныңыз кейін сіз үшін ұялмауы үшін күйеуіңіздің отбасын бақытты етуіңіз керек". Бұл тілектерді қонақтар үйлену күні қалыңдыққа айтқан. Қалыңдыққа айтылған бірнеше сөз өте терең философияны жасырады. Ошақтың қамқоршысы әйел. Ер адам-отбасының тірегі. Әйел-қыздың, ананың, әпкенің басты рөлі-отбасына деген сүйіспеншілік, жұбайына қолдау көрсету, отбасын жалғастыру, балаларды тәрбиелеу, үйде жайлылық пен тыныштық құру.

90-жылдардың басында педагогикада ұлттық тәрбие мәселелері көтерілді. Бірақ әлем өзгеруде, адамдардың көзқарасы мен бала тәрбиесіне көзқарасы да өзгереді. Мүмкін, сондықтан да бүгінде отбасындағы ұлттық тәрбие мәселелеріне көп көңіл бөлінбейді. Мұның субъективті және объективті себептері бар. Халықтың қалаларға үлкен ағымы жүріп жатыр, ауылдарда әдет-ғұрыптар мен дәстүрлерді білетін аға буын өкілдері іс жүзінде жоқ. Мүмкін, сондықтан жастар арасында ажырасу жағдайлары жиілеп кетті, отбасын құрғысы келмеді, өйткені қазір "мен азаматтық некеде тұрамын" деп айту сәнге айналды. "Азаматтық некеде өмір сүру" тіркесі жақында сөйлеуде қолданыла бастады. Ал бұрын қазақ отбасыларында ажырасулар болған емес. Қазақ қоғамындағы отбасы өз негізінде әрқашан «Шаңырақ» ұғымымен сәйкестендірілді.

Отбасы бала кезінен бастап, жынысына қарамастан, ұлттық тәрбиенің барлық әдет-ғұрыптары мен дәстүрлерін сақтай отырып, балаларды тәрбиелеуі керек. Біздің балалар отбасынан көп нәрсе алады. Олар үшін ата-аналар идеал, олар қандай болмасын? Балабақшалар, ата-аналардың көмегінсіз және қолдаусыз мектеп, қоғамдар балаға толыққанды тәрбие бере алмайды.

Мектептерде, балабақшаларда, баланың тұрғылықты жері бойынша "ақсақалдар кеңестері", "әжелер кеңестері" қоғамдық бірлестіктерінің жұмыстарын енгізу, үлгілі отбасылармен кездесулер, осындай отбасылардың қатысуымен конкурстар өткізу, осы іс-шараларды БАҚ-та кеңінен жариялау қажет. Құрылған қоғамдық бірлестіктер басқа уәкілетті органдармен тығыз қарым-қатынаста жұмыс істеуі, балаларын тәрбиелеуде қиындықтары бар ата-аналарға қолдан келгенше көмек көрсетуі қажет.

Әр ұлттың өз әдет-ғұрпы мен салт-дәстүрі, бала тәрбиесіне өзіндік көзқарасы бар. Бірақ бірде-бір әке мен бірде-бір ана баласының жаман адам болып өскенін қаламайды. Айта кету керек, бұл біздің қоғамдағы әйел, көбінесе руханилықтың, тектілік пен тазалықтың терең мөріні ұстайды.

Қазақ мәдениетіндегі **бала тәрбиесінің мәселесі** – ұлттық болмыстың өзегін құрайтын, өткен мен бүгінді жалғайтын аса маңызды тақырып.

Қазақ дәстүрінде бала тәрбиесі тек ата-ананың емес, **бүкіл қауымның ортақ жауапкершілігі** ретінде қарастырылған. «Бала – адамның бауыр еті», «Ел болам десең, бесігіңді түзе» деген қағидалар арқылы ұрпақ тәрбиесіне ерте бастан ерекше мән берілген. Тәрбие бесіктен басталып, салт-дәстүр, әдет-ғұрып, ырым-тыйым, ауыз әдебиеті, мақал-мәтелдер арқылы жүзеге асқан.

Негізгі тәрбиелік құндылықтардың қатарында:

- **Үлкенді сыйлау, кішіге қамқор болу**
- **Ата-ананы құрметтеу**
- **Еңбекқорлық пен адалдық**
- **Ар-намыс, ұят, имандылық**
- **Елге, жерге деген сүйіспеншілік** ерекше орын алған.

Сонымен қатар қазақ мәдениетінде бала тәрбиесінде **жыныстық-жас ерекшелікке сай тәрбие** жүйесі қалыптасқан. Ұл бала – ел қорғауға, жауапкершілікке, батылдыққа баулынса, қыз бала – инабаттылыққа, ибалыққа, отбасы ұйытқысы болуға тәрбиеленген.

Алайда қазіргі кезеңде бала тәрбиесіне қатысты бірқатар **өзекті мәселелер** туындап отыр:

- Жаһандану мен цифрлық технологиялардың ықпалы ұлттық тәрбиенің әлсіреуіне әкелуі;
- Отбасы мен мектеп арасындағы тәрбиелік байланыстың босаңсуы;
- Дәстүрлі құндылықтар мен заманауи өмір салты арасындағы қайшылықтар;
- Ата-әже институтының тәрбиедегі рөлінің төмендеуі.

Бұл мәселелерді шешу үшін ұлттық тәрбиені **заманауи білім беру жүйесімен үйлестіру**, отбасы тәрбиесін күшейту, халықтық педагогиканы жаңаша форматта насихаттау маңызды. Қазақ мәдениетіндегі бала тәрбиесінің мәнін терең түсіну – рухани кемел, ұлттық сана-сезімі жоғары ұрпақ тәрбиелеудің негізгі шарты.

Егер қаласаңыз, осы тақырыпқа:

- ғылыми мақалаға кіріспе,
- қысқаша аннотация,
- эссе немесе баяндама,
- негізгі проблемалар мен шешу жолдар түрінде де дайындап бере аламын.

Қазіргі таңда «бала тәрбиесі» өзекті мәселе болып отыр. Баланы үйде ата-ана емес, планшет пен ғаламтор тәрбиелеп жатқандай. Бірі балаға көп көңіл бөлсе, бірі балаға уақыт таппай әлек. Қазіргі қоғамда болып жатырған «ажырасу» мәселесі осы бала тәрбиесіндегі олқылықтарға әкеледі.

Қазақ халқы қашанда бала тәрбиесіне ерекше мән берген. Себебі ертеңгі күні сол ұрпақтан елінің абыройын көтеретін, жерін қорғайтын нар тұлғалы азаматтар өсіп шығатынына сенген. Сол себепті ата-бабамыз «Отан – отбасынан басталады» деп бекер айтпаған. Балаға тәрбие отбасынан басталатынын және өте маңызды екенін аңғартуға болады. Қазіргі уақытта елімізде бала тәрбиесі өзекті мәселелердің бірі болып отыр. Егерде баланы отбасында ислам дінінде және салт-дәстүрге қанық қылып өсірсе, елімізде келеңсіз жағдайлар орын алмас еді.

Сан ғасырлар бойы қазақ отбасында әдет-ғұрып, салт-дәстүр, ұлттық құндылықтар қалыптасты. Өйткені, отбасы балаларымыздың басты тірегі, тәрбие көзі болады. Тәрбие беруде ата-ананың, аға ұрпақтың рөлі зор. Балалар алғашқы тәрбие сабақтарын өз отбасында алады.

Қазақ отбасындағы тәрбие үлкенге ізет, кішіге қамқорлық, өзара көмек пен сенім, бір-біріне деген адалдыққа негізделген. Отбасындағы үлкен ұлға үлкен жауапкершілікті жүктелді. Ол кішіге тірек, кенжесіне ата-анасымен бірге өмір сүретін және қартайған шағында оларға қамқор болатын мұрагер екенін үйрететін. Негізгі отбасылық мәселелерді отағасы шешетін. Ал мұндай жанұялар өте тату, тату-тәтті болды, оларды бұлай жоюға болмайтын, бір-біріне қолдау мен бірлік орнатқан.

Қазақ халқында ең қастерлі адамдар аталар мен әжелер болған. Халқымызда үлкеннің жолын кесіп өтуге болмайды, бұл құрметсіздіктің белгісі. Сонымен қатар, әйелдер

жасына қарамастан ерлер өкілдерінің жолын кесіп өтпеуге тырысады. Балаларды мұндай мінез-құлыққа ерте жастан бастап үйретеді.

Дәстүрлердің қоғам өміріндегі рөлі мына функциялар арқылы жүзеге асырылады:

- қоғамдық тәжірибені жинақтау, беру қызметі. Ол уақытпен кеңістікте беруді қамтамасыз етеді;
- дәстүрлер мен әдет-ғұрыптар әлеуметтік құндылықтарды қамтитындықтан, әлеуметтік тірек қызметі;
- адамдардың нақты мінез-құлқын әлеуметтік маңызды нормаларға жақындатуға көмектесетін реттеуші функция;
- адамның әлеуметтік тәжірибені тікелей игеруін қамтамасыз ететін әлеуметтену функциясы.

«Ұлт боламын десек, бесігіңді түзе» – деп М. Әуезов айтқандай қазақ тәрбиесінде бесіктің орны бөлек. Сәби кезінен бесікке жатқан бала бесіктен түрлі жыр-дастанды, тәрбиелік маңызы бар ертегі, өлеңдерді естиді. Халық арасында ауыздан ауызға көшіп ел арасында таралып кеткен бесік жырында діни өлеңдер, үлгілі әңгімелер бар. Бесік жырының мақсаты баланы тыныштандыра отырып, баланың санасына ұлттық тәрбиенің, діннің нәрін сіңіру. Бесік жырында Алланы мадақтап дін туралы хабар берген, салт-дәстүрден және батырдың жыр-дастанына жақсы әңгімелерге сәби кезден қанып өскен. Осы тұста қазақ халқы баланы бес жасқа дейін патшаңдай көріп, мейрімді болу керектігін үгіттеген. Бес жастан он үшке дейін жұмсауды бұйырып, он үштен кейін өзіңмен теңдей досшы сырласа біл деп насихат айтқан.

Қазақ елі баланы тәрбиелеуді басты назарға ұстаған. Он үш жаста отау иесі қылып, он бес жасында елді басқаратын дәрежеге жеткізген. Халқымыз не ексең, соны орасың деп бекер айтпаса керекті. Сәби бала ошақ қасында қандай тәрбие көрсе өскенде де солай болатыны ақиқат. Егер бала отбасында мейірімге толы дінге қанық, салт-дәстүрмен тәрбиеленіп өссе болашақта еліне, жеріне қызмет ететін жақсы азамат болатыны анық. Ұл бала өсірсе баланың тәрбиесіне әкесі немесе ағалары көңіл бөлген, ұл баланы тәрбиелеген кезде де дұрыс мәміле құрып, баланы төзімділікке және еңбекке баулып өсірген. Өтірік айтпауға, біреудің ала жібін аттамауға, ұрлық жасамауға баулыған. Қыз баланың тәрбиесіне анасы, жеңгесі немесе әжесі көңіл бөліп ибалы, инабатты қылып тәрбиелеген. Қыз айттырсада, құда түсседе қыздың жанында әрдайым жеңгесі жүретін болған. Қызға азды-көпті ақыл кеңесін айтып, қыз баласын жігітпен жолықтырсада жеңгесі қасынан табылып отырған. Осындай тәрбиенің арқасында қыз аттаған босағасында абыройлы болған. Қазіргі таңда жас қыздар босаға аттамай тұрып ия болмаса мектеп кезінде – ақ некесін қидырмай екі қабат болып жатқаны қаншама. Үйінде естімеген жылы сөзін ғаламтор желісіндегі жігіттен сүйдім-күйдім деген басқада жылы сөздерін естіп алданып қалып жатқан қыздарымыз жетерлік. Жоғарғыда айтқандай ақ жаулықты әжесі, анасы жылы сөзін төгіп қызды тәрбиелесе өскен кезде жеңгесі әрдайым жанынан табылып ақыл-кеңесін айтып жүрсе бұндай жағдай болмайтыны анық.

Ал қазіргі кезде жас отбасы баламыз біз көрген қиындықты көрмесін, таршылықты сезінбесін деген желеумен балаларына қалаған нәрселерін әпереді. Осы тұста осалдық танытып жатқанын түсінбейді, саналық тұрғыдан да балаға қалағанын әперу машақатсыз келген нәрселер баланы еріншектікке және жаман әдетке тәрбиелейтіні анық. «Шайнап берген ас болмас» деп қазақ халқы айтқандай әр бір келген дүниенің бала үшін құны болмай қалатыны тағы бар. Осыдан кейін бала үшін әрбір нәрсе ақшамен теңеліп, бала барлығын ақшамен сатып алынатындай көрінеді, кейбір дүниелер ақшасыз келетінін бала түсінбей өседі. Көк тиын құны жоқ болған «мейірім», «шапағат», «бауырмашыл», деген дүниелерді бала сезінбей өседі. Бұндай нәрселерден алшақ өскен бала үшін әке-шешесіне қарау, мейірімін төгу деген нәрселерде сараңдық танытады. Қарттар үйінің көбеюі, әке-шешесін

апарып тастауы қазіргі таңда ерсі қылық болмай қалғаны ащыда болса шындық. Жастардың рухани байлығы тым төмен болса, олардан елге де, жұртқа да, ертеңгі келешекке де мардымды пайда әкелмесі анық. Жақсы жардың қадірін білмейтін жаман еркектер, ер қадірін білмейтін жайсыз әйелдер қайдан шығып жатыр? Осы рухани құндылықтың жоқтығынан шығып жатыр.

Қорытындылайтын болсақ, қазақ мәдениетіндегі бала тәрбиесі – ұлттың рухани негізін құрайтын, ұрпақтан-ұрпаққа жалғасқан құндылықтар жүйесі. Дәстүрлі тәрбиенің басты мақсаты – елін, жерін сүйетін, рухани кемел, жауапкершілігі жоғары тұлға қалыптастыру.

Қазіргі жағдайда ұлттық тәрбиені заманауи білім беру жүйесімен үйлестіру, отбасы тәрбиесін күшейту, халықтық педагогиканы жаңаша форматта насихаттау маңызды. Қазақтың дәстүрлі бала тәрбиесін сақтау мен дамыту – ұлттық болмысты сақтаудың және болашақ ұрпақтың рухани тұтастығын қамтамасыз етудің негізгі шарты.

Әдебиеттер тізімі

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ҚАЗІРГІ ЗАМАНҒЫ ҚОҒАМДАҒЫ ДЕМОКРАТИЯЛЫҚ ҚҰНДЫЛЫҚТАРДЫҢ РӨЛІ

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Философия ғылымдарының магистрі, «Гуманитарлық ғылымдар» кафедрасының оқытушысы, Қазақстан, Абай атындағы Қазақ ұлттық педагогикалық университеті

Аннотация. Мақалада демократиялық қоғамдағы сана еркіндігі ұғымы философиялық және әлеуметтік-теориялық тұрғыда талданып, оның қоғамдық тұрақтылықты қамтамасыз етудегі рөлі ашылады. Автор Қазақстандағы демократиялық үдерістердің қалыптасу ерекшеліктерін, жергілікті өкілді органдардың әлеуметтік құрамын және қоғамдық сананың даму деңгейін сараптайды. Сондай-ақ шетелдік демократиялық даму үлгілеріне салыстырмалы талдау жасалып, демократиялық институттарды жетілдіруге бағытталған нақты ұсыныстар ұсынылады. Мақала демократиялық реформаларды ұлттық менталитет пен саяси мәдениет ерекшеліктерін ескере отырып жүзеге асыру қажеттігін негіздейді.

Аннотация. В статье анализируется понятие свободы сознания в демократическом обществе в философском и социально-теоретическом контексте, раскрывается его роль в обеспечении общественной стабильности. Автор анализирует особенности формирования демократических процессов в Казахстане, социальный состав местных представительных органов и уровень развития общественного сознания. Также будет проведен сравнительный анализ моделей зарубежного демократического развития и предложены конкретные предложения, направленные на совершенствование демократических институтов. Статья обосновывает необходимость осуществления демократических реформ с учетом особенностей национального менталитета и политической культуры.

Annotation. The article analyzes the concept of freedom of consciousness in a democratic society in philosophical and socio-theoretical terms and reveals its role in ensuring public stability. The author analyzes the features of the formation of democratic processes in Kazakhstan, the social composition of local representative bodies and the level of development of public consciousness. A comparative analysis of foreign models of democratic development is also carried out and specific proposals are proposed aimed at improving democratic institutions. The article substantiates the need to implement democratic reforms taking into account the peculiarities of the national mentality and political culture.

Кілт сөздер: демократия, сана еркіндігі, менталитет, саяси мәдениет, мәслихат, жергілікті басқару, азаматтық қоғам.

Ключевые слова: демократия, свобода сознания, менталитет, политическая культура, маслихат, местное самоуправление, гражданское общество.

Keywords: democracy, freedom of consciousness, mentality, political culture, maslikhat, local government, civil society.

Философиялық және әлеуметтік ғылымдарда сана еркіндігі жеке тұлғаның ойлау, таңдау және жауапкершілік қабілетімен тығыз байланысты ұғым ретінде қарастырылады. И. Кант еркіндікті моральдық заңға бағынған жауапты әрекетпен ұштастырса, Г. Гегель еркін сананы қоғамдық институттар арқылы жүзеге асатын тарихи процесс деп сипаттайды. Әлеуметтік философия мен социологияда (М. Вебер, Э. Дюркгейм) сана еркіндігі қоғамның құндылықтық жүйесімен, билік құрылымдарымен және мәдени дәстүрлерімен сабақтас құбылыс ретінде түсіндіріледі.

Демократия теориясында да еркіндік ұғымы абсолютті мәнге ие емес. Ш. Монтескье билік тармақтарының тепе-теңдігін еркіндіктің кепілі ретінде қарастырса, А. Токвиль демократиялық қоғамда еркіндік қоғамдық мораль мен саяси мәдениетке сүйенгенде ғана тұрақты болатынын атап көрсетеді. Осы тұрғыдан алғанда, сана еркіндігі қоғамның тарихи дамуына, менталитетіне және азаматтық тәрбиесіне сәйкес реттеліп отыратын әлеуметтік құндылық болып табылады.

Қазіргі жаһандану жағдайында демократиялық қоғам құру мәселесі көптеген мемлекеттер үшін стратегиялық маңызға ие болып отыр. Демократия тек саяси институттар жүйесі ғана емес, сонымен қатар қоғамдық сананың, азаматтық жауапкершіліктің және құқықтық мәдениеттің белгілі бір деңгейін талап ететін әлеуметтік феномен. Осы тұрғыдан алғанда, демократиялық дамудың өзегінде тұрған негізгі ұғымдардың бірі – сана еркіндігі.

Сана еркіндігі демократиялық қоғамның тұрақтылығы мен дамуының іргелі алғышарты ретінде қарастырылады. Алайда еркіндіктің мөлшері, оның қоғамдық санаға, менталитетке және басқару тетіктеріне тәуелділігі әрбір елдің тарихи даму ерекшеліктеріне байланысты әртүрлі сипат алады. Қазақстан сияқты жас, нарықтық-демократиялық даму жолындағы мемлекет үшін сана еркіндігі мәселесі ерекше өзектілікке ие. Себебі демократиялық институттарды қалыптастыру барысында қоғамның ішкі тұрақтылығын сақтау, ұлттық менталитетті ескеру және басқару тиімділігін қамтамасыз ету қажеттілігі туындайды.

Бұл мақалада демократиялық қоғамдағы сана еркіндігінің рөлі философиялық-теориялық тұрғыда талданып, Қазақстандағы демократиялық үдерістердің қазіргі жағдайы мен даму ерекшеліктері сараланады. Сонымен қатар демократиялық институттарды жетілдірудің негізгі бағыттары ұсынылады.

Демократиялық қоғамның іргелі категорияларының бірі – **сана еркіндігі**. Философиялық тұрғыдан алғанда, сана еркіндігі жеке тұлғаның ойлау, таңдау және жауапкершілік қабілеттерімен тығыз байланысты. Мәселен, И. Кант еркіндікті моральдық жауапкершілікпен ұштастырса, Г. Гегель еркін сананы қоғамдық институттар арқылы іске асатын тарихи құбылыс ретінде қарастырады. Ал әлеуметтік философияда (М. Вебер, Э. Дюркгейм) сана еркіндігі қоғамның мәдени, экономикалық және билік құрылымдары арқылы қалыптасатын құндылықтық феномен ретінде сипатталады.

Демократия ұғымы да тек саяси механизм емес, **қоғамдық сананың белгілі бір даму деңгейін талап ететін әлеуметтік жүйе** екені белгілі. Ш. Монтескьенің билік тармақтарының тепе-теңдігі туралы тұжырымдары, А. Токвильдің демократия мен қоғамдық мораль арасындағы байланысқа берген бағасы демократиялық қоғамда сана еркіндігінің шектен тыс немесе жеткіліксіз болуы қоғам тұрақтылығына кері әсер ететінін дәлелдейді.

Осы тұрғыдан алғанда, сана еркіндігі абсолютті емес, **қоғамның тарихи дамуына, менталитетіне және саяси мәдениетіне сәйкес реттеліп отыратын құндылық** ретінде қарастырылуы тиіс.

Қоғамдағы демократия – ол еркіндік, конституция мен заң шеңберіндегі сана еркіндігі. Сана еркіндігінің негізгі қозғаушы күштерінің бірі – материалдық құндылық пен билік. Содан кейін барып дәстүрлі менталитет және басқа да негіздер орын алады. Кез келген саналы адамның ой еркіндігінің демократиялық қоғамның дамуына сәйкес ұстанымдары болуы шарт.

Демократиялық қоғамда сана еркіндігінің мөлшері болуы керек пе? Бұл демократиялық қоғамның даму деңгейіне байланысты. Сана еркіндігінің мөлшері соған сәйкес болады.

Сана еркіндігі – тұрақтылық кепілі, қоғамның тұрақтылық эталоны. Егер еркіндік мөлшері қалыпты деңгейден асып кетсе немесе кеміп кетсе қоғамның дамуына кері әсер етеді. Демократиялық үдерістердің, яғни сана еркіндігінің мөлшері қоғамның дамуына, яғни сананың тәрбиеленуіне сәйкес оң бағытта өзгеріп отыруы тиіс. Оны мұқият реттеуші тетік болғаны абзал. Біз сияқты нарықтық-демократиялық даму жолындағы жас мемлекет үшін бұл – қажеттілік.

Сана менталитетке тәуелді. Ол жылдар бойы қалыптасады. Бізге Американың немесе Еуропа демократиясының түпнұсқасын көшіруге болмайды. Оларда ғасырлар бойы демократиялық қоғамның тезінен өткен америкалық сана еркіндігі, қалыптасқан өзіндік менталитеті бар. Оны бізге көшіріп алып келсек, қоғамдағы тұрақтылықты, қалыпты жағдайды бұзуы мүмкін. Біздің кейбір «демократтарымыз» халықтың атынан «Халық шешуі керек», «Халықтың таңдауы болсын» дегендей әңгімелерді көп айтады. Халықты жалау етеді. Бұл сана еркіндігінің қалыпты мөлшеріне әсер ететінін ойламайды. Түптеп келгенде, мұндай әрекеттер тұрақсыздыққа әкелуі мүмкін екенін ескермейді. (1,45.)

Ол ұрандардың да уақыты бірте-бірте келер. Ал бүгінгі уақыттың өз шындығы бар. Ежелгі Ұлы дала демократиясының негізгі қағидаларына кеңестік саясаттың ықпалы әлі де байқалады. Қазірше регрессивті рушылдық, ұлтшылдық сана басымдыққа ие екені анық. Демократиялық үрдістердің қоғамда дұрыс қалыптасуы, сана еркіндігінің бірте-бірте артуы қоғамның тәрбиелену деңгейіне тікелей байланысты.

Жоғарыда атап өткеніміздей, сана еркіндігі материалдық құндылық пен билікке тәуелді, яғни басқару тетігінің негізгі құралы болып отыр. Қоғамға тиімдісі, әрине, билік тетігі, ал материалдық тетік қоғамды бөлшектеп жіберуі айқын және соның нәтижесінде материалдық құндылық билік тетігіне үстемдік жасау қаупі орнайды да, мемлекеттің қауіпсіздігіне нұқсан келуі әбден мүмкін.

Сонымен қоғамның тұрақты дамуының, әсіресе жас мемлекеттер үшін демократиялық үдерістердің міндетті түрде басқару тетігі болуы шарт және оның билік тарапынан басқарылуы аса маңызды. Ал енді осы демократиялық жағдайлардың Қазақстандағы деңгейі және қоғамның осы үдерістерге әсері немесе оны қалай қабылдауы туралы ой жүгіртетін болсақ, оның оң сипатын аңғарамыз. Осы орайда елімізде демократиялық үрдістерді жетілдірудің келесі қадамы – ауыл әкімдерінің сайлауы. Бұл құптарлық үдеріс. Келешекте аудан және облыс әкімдерін де сайлап қоюымыз керек. Әкімдерді сайлау мандаты мәслихат депутаттарына берілуі – құптарлық жағдай. Халықтың тікелей дауыс беруі арқылы сайланған мәслихат депутаттары көпшіліктің еркін білдіре алады.

Біз халықтың санасы бүгінгі қоғамдағы демократиялық жағдайдағы сайлауға қаншалықты дайын екендігіне ерекше мән беруіміз керек. Бүгінгі мәслихат депутаттарының құрамына назар салайық. Көпшілік өңірлерге тән бір мәселе бар. Депутаттардың басым көпшілігі шағын және орта бизнес өкілдері. Бұл, жоғарыда атап өткеніміздей, сана еркіндігіне материалдық құндылықтың басымдығы әсер етіп отырғанын көрсетеді. Депутаттардың құрамында зиялы қауым өкілдері мүлдем аз, кей жерлерде жоқ деп айтуға болады. Бұл қоғамның дұрыс бағытта дамуына, сананын демократиялық үдерістерге сәйкес қалыптасуына нұқсан келтіреді. Сондықтан болашақта жергілікті мәслихаттардың депутаттарын сайлауды

партиялық тізіммен өткізгеніміз дұрыс бола ма, деген ой келеді. Зиялы қауым өкілдерін де көбірек қамтуды ойластыратын кезең жетті.

Қазіргі мәслихат депутаттарының басым бөлігі шағын бизнес өкілдері болып отырғандығы демократиялық институттардың дамуына кедергі келтіруде. Сана тәрбиесінде тосқауылдық-кертартпалық әрекеттерге итермелеуде. Сана регрессивті тәрбиеленіп жатыр деуге болады.

Мәслихат депутаттарының құрамында руханият өкілдерінің, яғни интеллектуалды топ – дәрігер, мұғалім, өнер-мәдениет қайраткерлері, жазушы-журналистер, заңгерлер, ғалымдар, жастар, мемлекеттік емес ұйымдардың және т.б. өкілдері тым аз болғандығының зияны шаш-етектен. Бұл топ – билік пен халықтың арасын байланыстыратын алтын көпір. Сонымен бірге мемлекеттік қызметке шыңдалған кадрларды даярлау мәселесі де ақсай бастайды деген ой белең алуда.

Ал партиялық тізімді жасақтаушылар бұл іске үлкен жауапкершілікпен қарауы тиіс. Таңдау барысында үміткердің тазалығына, қоғамдық деңгейдегі жұмыстарымен елге танылуына көңіл бөлген жөн. Сол сияқты, сауалдамалық ұстанымдарды алға тарта отырып, сараптама жасаған дұрыс. Оны объективті өткізу алгоритмін жасау да аса қиын емес. Яғни сайлау институттары (Сенат, Мәжіліс, мәслихат) арқылы елдегі таза адамдарды билікке жақындату – бүгінгі таңдағы ең өзекті мәселелердің бірі.

Сондай-ақ сайлау жүйесіндегі мәслихаттар институтының бүгінгі таңдағы депутаттардың құрамдық болмысына талдау жасасақ, ойландыратын жағдайлар баршылық. Ол неде? Депутаттық құрамның басым бөлігі, негізінен, қалталы азаматтар. Ал енді сол азаматтардың бірқатары қарапайым ел мүддесінің қорғаушысы немесе қолдаушысы деп толыққанды айту қиын. Бұл мәселелер көп жағдайда тек сайлауалды бағдарламалар деңгейінде ғана қалып отыр.

Бүгінгі ақпарат беттеріндегі халықтың әлеуметтік мәселелерінің қайнаған ортасында мәслихат депутаттарының көрінбеуі де біраз жайттың бетін ашатындай. Бүгінгі таңда қарапайым халықтың ділі (менталитеті) қоғамдағы өзгерістерге дайын болмай тұр. Өкінішке қарай материалдық құндылықтарға тәуелділік сана құндылығынан басым. Рулық сананың субъективтіліктің құралы болуы қоғамымыздағы демократиялық институттарымыздың дамуына үлкен кедергі келтіруде. Себебі біз ауыл әкімдерін таңдауды мәслихаттарға берудің қадамдарын жасадық. Ертең аудан, облыс деңгейіне жеткенде бұл үдеріске әсер ету мүмкіндігіміздің шектелу қаупі де жоқ емес. Бұл дегеніміз – жергілікті аймақтардағы ұйымдасқан қылмыстық топтардың ықпалында кетіп қалу қаупін білдіреді. Сондықтан билікте демократиялық институттарды назарда ұстау тетіктерінің болуы өте маңызды.

Мәслихаттарда қарапайым халықтан шыққан зиялы қауым өкілдерінің аздығы болашақта үйіткілдер туындатпасына кім кепіл?!

Біз – дамушы қоғамбыз. Олай болса, экстремальды «дағдарыстық» жағдайларға төзімділігімізді қалыптастыруымыз қажет. Ол үшін мәслихат институттарының қоғаммен өте тығыз қарым-қатынаста болуын қамтамасыз етуіміз керек. Ал енді бүгінгі жағдайда қарапайым халық өкілдерінің депутаттыққа сайлану мүмкіндігі жоқтың қасында. Олардың жоғарыда айтқан бизнесмендер секілді материалдық ресурсы жоқ. Не істеу керек?

Меніңше, мұндағы мәселені шешудің бір-ақ жолы бар, ол – мәслихат депутаттарын сайлаудың форматын Мәжіліс сайлауындағыдай партиялық тізім арқылы өткізу. Партиялық тізімге енетін азаматтарды таңдау барысында объективті сараптау арқылы тұрашылдық таныта білсек, бұған партиялардың, үкіметтік емес ұйымдардың қатысуын қамтамасыз етсек мәселені еңсереміз.

Демократиялық қоғам құрудың басты құндылығының бірі онда өмір сүріп жатқан адамдарды заң талаптары шеңберіндегі сана еркіндігіне тәрбиелеуден басталады.

Санамыздың еркіндік мөлшерін демократиялық институттар арқылы тәрбиелейік. Мәңгілік ел идеясымен жаңа дәуірге қарыштай қадам басайық. Тәуелсіз мемлекетіміздің жаһандық демократиялық 30 елдің қатарында болуына атсалысайық.

Қазақстандағы демократиялық дамудың өзіндік тарихи-әлеуметтік ерекшеліктері бар. Кеңестік кезеңнен кейінгі қоғамда патерналистік сана, рулық-туыстық қатынастар және материалдық мүдделердің басымдығы ұзақ уақыт бойы сақталып келді. Бұл жағдай демократиялық институттардың, әсіресе жергілікті өзін-өзі басқару жүйесінің баяу қалыптасуына ықпал етті.

Соңғы жылдары ауыл әкімдерін сайлау тәжірибесінің енгізілуі азаматтардың саяси белсенділігін арттыруға бағытталған маңызды қадам ретінде бағаланады. Дегенмен мәслихат депутаттарының әлеуметтік құрамына талдау жасайтын болсақ, олардың басым бөлігін шағын және орта бизнес өкілдері құрайтыны байқалады. Бұл қоғамдағы материалдық құндылықтардың сана құндылықтарынан басым түсу үрдісін көрсетеді.

Зиялы қауым өкілдерінің – ғалымдар, мұғалімдер, дәрігерлер, мәдениет және өнер қайраткерлерінің, жастар мен азаматтық сектор өкілдерінің – мәслихаттардағы үлесінің төмен болуы демократиялық мәдениеттің толық қалыптасуына кедергі келтіреді. Өйткені дәл осы әлеуметтік топ билік пен қоғам арасындағы байланысты қамтамасыз ететін маңызды медиаторлық қызмет атқарады.

Әлемдік тәжірибе көрсеткендей, демократиялық институттардың тиімділігі елдің тарихи даму жолына және қоғамдық сана деңгейіне тікелей байланысты. АҚШ пен Батыс Еуропа елдерінде демократиялық жүйе бірнеше ғасыр бойы эволюциялық даму жолынан өтті. Бұл мемлекеттерде азаматтық жауапкершілік пен құқықтық мәдениет берік орныққан.

Ал Шығыс Азия елдерінің (Оңтүстік Корея, Сингапур) тәжірибесі демократиялық реформалардың бастапқы кезеңінде басқарылатын демократия тетіктерінің маңыздылығын көрсетеді. Қазақстан үшін бұл тәжірибелер демократиялық институттарды ұлттық менталитетке және қоғамның дайындық деңгейіне бейімдеп енгізудің қажеттігін айқындайды.

Демократиялық үдерістерде тепе-теңдік сақталмаған жағдайда қоғам үшін бірқатар қауіп-қатерлер туындайды. Сана еркіндігінің шектен тыс кеңеюі рулық, аймақтық және материалдық мүдделердің үстем болуына әкелуі мүмкін. Ал демократиялық институттардың шамадан тыс шектелуі азаматтық енжарлық пен саяси апатияны күшейтеді.

Қазақстан жағдайында жергілікті сайлау институттарының ықпалды топтардың немесе ұйымдасқан құрылымдардың бақылауына түсу қаупі де назардан тыс қалмауы тиіс. Сондықтан демократиялық институттарды дамыту оларды реттеу және бақылау тетіктерімен қатар жүруі қажет.

Қазақстандағы демократиялық үдерістерді жетілдіру мақсатында мәслихат депутаттарын сайлау жүйесін партиялық тізім негізінде жүзеге асыру, зиялы қауым мен жастар үшін әлеуметтік квоталар енгізу, сондай-ақ азаматтық білім беру бағдарламаларын жүйелі түрде дамыту маңызды болып табылады. Бұл шаралар демократиялық институттардың мазмұндық тұрғыдан дамуына ықпал етеді.

Қорытындылай келе, демократиялық қоғам құру – саяси реформалармен ғана шектелмейтін, ең алдымен қоғамдық сананы тәрбиелеуге бағытталған ұзақ мерзімді үдеріс. Сана еркіндігі заң шеңберінде, жауапкершілікпен және ұлттық менталитетті ескере отырып дамыған жағдайда ғана қоғам тұрақтылығының кепілі бола алады.

Қазақстан үшін демократиялық институттарды дамыту эволюциялық жолмен, басқару тетіктерімен үйлестіріле отырып жүзеге асуы тиіс. «Мәңгілік ел» идеясы демократиялық құндылықтарды ұлттық рухани негіздермен ұштастырудың символы ретінде қоғамдық сананың жаңаруына қызмет етеді. Осы бағытта жүйелі әрі ғылыми негізделген саясат жүргізу еліміздің әлемдік демократиялық қауымдастықтағы орнын нығайтуға мүмкіндік береді.

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Philological Sciences

THE ROLE AND BENEFITS OF LEARNING DIFFERENT SECOND FOREIGN LANGUAGES IN TOURISM CAREERS

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Annotation. *This article examines the pivotal role of multilingualism in shaping tourism careers and highlights the benefits of learning different second foreign languages. It argues that language proficiency is not only a personal asset but also a strategic necessity in a globalized tourism industry. The study emphasizes how multilingual skills enhance employability, service quality, cultural competence, and international mobility across diverse sectors such as hospitality, travel agencies, tour guiding, and event management.*

Key words: *multilingualism, second foreign languages, employability, cultural competence, international mobility, language proficiency*

Introduction. The tourism industry stands as one of the most dynamic and globally interconnected sectors. As millions of travelers cross borders each year, the ability to communicate across languages and cultures has become a defining skill for tourism professionals. Multilingualism is not merely a personal asset; it is a strategic advantage that enhances employability, service quality, cultural competence, and international mobility within tourism-related professions such as hospitality, travel agencies, tour guiding, and event management.⁽¹⁾

This work is a comprehensive analysis of how learning different second foreign languages shapes careers in tourism. It explores the ways in which multilingualism enhances employability, communication, and cultural competence; examines the alignment of language skills with specific tourism markets and sectors; and presents real-world examples of how language proficiency impacts career advancement, guest satisfaction, and international work opportunities.

The international nature of tourism necessitates cross-cultural communication between individuals from diverse linguistic backgrounds. Companies in the sector actively seek graduates and employees who are linguistically competent in foreign languages to meet the demands of an increasingly globalized market. Multilingualism in tourism is not limited to English, the global lingua franca, but extends to a range of second and third languages that align with key source markets and regional visitor flows. The ability to master another language is essential for career development, as it enables professionals to interact effectively with international guests, partners, and colleagues, and to adapt to the evolving needs of the industry.

Multilingualism is in demand in the tourism labor market. Employers consistently report that proficiency in one or more foreign languages is a major criterion for hiring, especially in roles that involve direct guest interaction or international business dealings. For example, a recent OECD study found that in Europe, knowledge of English was explicitly required in 22% of all online job vacancies, with German, Spanish, French, and Mandarin Chinese also in demand, particularly

for managerial and professional roles.(2) Recent academic and industry studies confirm that multilingualism is a cornerstone of tourism careers. Bilodid (3) identifies foreign language skills as the primary driver of career success in hospitality and tourism, emphasizing that smooth communication enables stronger business connections and competitiveness in the labor market. Misno, Mohd, and Rahman (4) demonstrate that mastering two or more languages reduces communication barriers and is perceived by tourism students in Malaysia as a clear advantage for career advancement. Industry reports also reinforce these findings. The OECD (2022) notes that in Europe, English was explicitly required in 22% of online job postings, while German, Spanish, French, and Mandarin Chinese were increasingly demanded for managerial and professional roles. A hotel industry survey (CEFR, 2023) found a nearly linear relationship between language proficiency and perceived service quality, with B2 level identified as the minimum requirement for above-average performance. Together, these studies demonstrate that multilingualism is not only a personal asset but a strategic necessity for employability, guest satisfaction, and international mobility in tourism careers.

Key findings from industry and academic research include:

- Only candidates with strong oral and written communication skills in foreign languages tend to be recruited for tourism and hospitality positions.
- Multilingual employees are more likely to be promoted to supervisory or managerial roles, as they can negotiate contracts, handle international clients, and represent their organizations abroad.(5)
- Language skills are increasingly seen as a form of human capital, associated with higher employability, mobility, and, in some cases, wage premiums.

Effective communication is the cornerstone of guest satisfaction in tourism. Multilingualism enables professionals to interact with guests in their native languages, fostering trust, comfort, and a sense of being valued. Research shows that guests report greater satisfaction when staff can communicate in their language, which in turn leads to higher rates of repeat business and positive reviews.

Key communication benefits include:

- Personalized service: multilingual staff can give recommendations, resolve issues, and anticipate guest needs more effectively.
- Reduced misunderstandings: Language barriers often lead to miscommunication, errors, and guest dissatisfaction. Proficiency in the guest's language minimizes these risks.
- Emotional connection: speaking a guest's language demonstrates respect and cultural sensitivity, strengthening the emotional bond between guest and host.

Language proficiency is closely linked to perceptions of professionalism and service quality. A study on language barriers in hotels found a nearly linear relationship between language proficiency and perceived service quality, with a B2 level (upper-intermediate) on the Common European Framework of Reference (CEFR) emerging as the minimum requirement for above-average performance.(6) Dimensions such as empathy, reliability, responsiveness, and assurance are all positively influenced by higher language proficiency.

Different tourism sectors require distinct language skills and proficiencies, aligned with the nature of guest interaction and business operations. Accommodation and hospitality roles prioritize speaking and listening skills for guest interaction, check-in/out, and problem-solving. Travel agencies require strong writing and reading skills for preparing itineraries, contracts, and correspondence. Tour guides need advanced speaking and storytelling abilities, often in multiple languages, to engage diverse groups and provide immersive experiences. Event managers and destination marketers benefit from negotiation and presentation skills, as well as the ability to create content in target market languages.

Conclusion. Multilingualism is a cornerstone of success in tourism careers. As the industry continues to globalize and diversify, the ability to communicate across languages and cultures is not just a desirable skill—it is a strategic necessity. Professionals who invest in learning second (and third) foreign languages gain a competitive edge in employability, career advancement, guest satisfaction, and international mobility.

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აბსტრაქტულ-ფიგურატიული მეტარეალიზმის დეკლარაცია: სახვითი ხელოვნების თანამედროვე მიმდინარეობის შემდგომი კვლევა და ანალიზი

The Art Declaration of Abstract-Figurative Metarealism: Further Research and Analysis of the Contemporary Fine Art Movement

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სახელმწიფო უნივერსიტეტი, მეცნიერებათა და ხელოვნების ფაკულტეტი

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Annotation:

The present article consolidates and expands my prior research, analysis, and findings related to the formulation of Abstract-Figurative Metarealism — a contemporary fine art movement. Although the concept of metarealism had previously appeared in philosophical and cultural theory, it had not been scientifically defined as a distinct fine art movement. After publishing my first scientific publication on Abstract-Figurative Metarealism in 2024, followed by a second one in 2025, the given 2026 study further examines the movement's conceptual foundations through theoretical inquiry, comparative analysis with realism, surrealism, magic realism, abstraction, and reflection on artistic practice. Abstract-Figurative Metarealism is defined as an approach that does not negate reality but reveals its multilayered structure by integrating rational and irrational perception, abstraction and figuration, and the unconscious, preconscious, conscious, and — most importantly — superconscious levels of experience. The article suggests that this art movement represents a distinct mode of artistic thinking and intuitive insight rather than a stylistic hybrid. Abstract-Figurative Metarealism positions art as a form of research and knowledge production. By consolidating theoretical discourse and artistic methodology, the study situates Abstract-Figurative Metarealism within contemporary art as an evolving and independent fine art movement.

keywords: new art movement, painting, abstract-figurative metarealism, art philosophy, artist lifestyle, expression of superphysical nature, research into superconscious imagery, modern art, art and science, art theory, contemporary art practice

სახვით ხელოვნებაში, უშუალოდ ფერწერაში, აბსტრაქტულ-ფიგურატიული მეტარეალიზმის მხატვრული მიმდინარეობის ფორმულირება დავიწყე ორი წლის წინ. იმისათვის რომ ჩამომეყალიბებინა ამ მიმდინარეობის სახელწოდება, გამოვიკვლიე არსებული მიახლოებული სხვა მიმდინარეობები, როგორიცაა სიურრეალიზმი და Pittura Metafisica (იტალიურიდან — მეტაფიზიკური ფერწერა), და აღმოვაჩინე მიხაილ ეპსტეინის ფილოსოფიურ-კულტურული ნაშრომი “თეზისები მეტარეალიზმსა და კონცეპტუალიზმზე” (1983 წ.), სადაც მეტარეალიზმის კონცეფცია მოცემულია პოსტმოდერნიზმის ფართო კონტექსტში. ტერმინი მეტარეალიზმი იყო თეორიულად წარდგენილი კულტურულ-ლიტერატურულ კონტექსტში, და ეპსტეინის მიხედვით იყო განსაზღვრული როგორც ისეთი შინაარსის მატარებელი კონცეფცია რომელიც არ ცილდება რეალობას, არ ანადგურებს მნიშვნელობას, არამედ აღრმავებს მას. (Mikhail Epstein, 8 June 1983, Transl. Slobodanka Vladiv-Glover) მიუხედავად იმისა, რომ ეს ტერმინი ადრე უკვე ფიგურირებდა თეორიულ დისკურსში, ჩემ კვლევაში აღნიშნული კონცეფცია ჩამოყალიბებულია და დასაბუთებულია როგორც დამოუკიდებელი **მხატვრული პრაქტიკა სახვით ხელოვნებაში**.

ამ ეტაპზე მე ვიყენებ უკვე არსებულ ფილოსოფიურ ტერმინს, იმისათვის, რომ დავადეკლარო ის სახვითი ხელოვნების მიმდინარეობა, რომელსაც ვავითარებ. ჩემი სტილის კვლევისას მივედი დასკვნამდე, რომ ამ მიმდინარეობას ყველაზე ზუსტად შეესაბამება სახელწოდება აბსტრაქტულ-ფიგურატიული მეტარეალიზმი, სიტყვა მეტა-ს მნიშვნელობიდან გამომდინარე — როგორც რეალობის მიღმა მდგომი, ზემოდან დანახული და მრავალდონიანი აღქმის ფორმა. “meta-word-forming element of Greek origin meaning 1. after, behind; among, between, 2. changed, altered, 3. higher, beyond;” (Etymonline.com, February 4, 2026). აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არ უარყოფს რეალობას, არამედ გადის მის მიღმა და ამჟღავნებს მის ფენებს. აქ არის ირაციონალურისა და რაციონალურის შერწყმა, **აბსტრაქციისა და ფიგურატიულის გადაკვეთა**; ქვეცნობიერის, ცნობიერის და ზევცნობიერის შეთანხმებული მოქმედება, რომელიც რეალობის მრავალი შრისა და დონისგან ქმნის უნიკალურ ვიზუალურ-შემოქმედებით რეალობას — აბსტრაქტულ-ფიგურატიულ მეტარეალიზმს. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არის ის რეალობა რომელიც ვლინდება ასეთი კომპლექსური აზროვნების შედეგად.

შეიძლება ითქვას, რომ მეტარეალიზმისა და სიურრეალიზმის შედარებისას ძირითადი დამაბნეველი ნიუანსი ხშირად უკავშირდებოდა იმას, რასაც საღვადო დალი „ჰიპნაგოგიურ გამოსახულებებს“ — hypnagogical images — უწოდებდა, ცოცხალ ვიზუალურ ან სენსორულ გამოცდილებებს, რომლებიც ჩნდება ღვიძილსა და ძილს შორის გადასვლისას. (Dalí, 1971, 3:8-3:12) მაშინ, როცა სიურრეალიზმში **ჰიპნაგოგიური გამოსახულებები** თავისი შინაარსით უკავშირდება ქვეცნობიერ დინებასა და ძილისკენ გადასვლას, აბსტრაქტულ-ფიგურატიულ მეტარეალიზმში **ჰიპნოპომპიური სურათები** — hypnopompic images — ვლინდება ცნობიერში, როგორც ზევცნობიერი გამოსახულებები ძილიდან გამოსვლისას. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი უფრო არის გაღვიძებული ადამიანის ცხად „სიზმარში“ მყოფის პოზიციიდან დანახული, ვიდრე სურათები, რომელიც ვლინდება მანამდე, სანამ ადამიანი იძინებს ან ძილში იმყოფება.

აბსტრაქტულ-ფიგურატიული მეტარეალიზმი განისაზღვრება, როგორც რაციონალურისა და არარაციონალურის ზღვარზე არსებული „მეტარეალისტური ფანჯრები“ ან „მეტარეალისტური პორტალები“, რომლებიც შეგვიძლია ავხსნათ, როგორც **ზეცნობიერი გამოსახულება**. ამგვარად ისეთი მხატვრული გამოსახულება, რომელიც არ შემოიფარგლება ქვეცნობიერი და ცნობიერი აღქმით და მიუთითებს

ცნობიერების ზემოთ ან მიღმა არსებულ შრეებზე. ინტუიციური, მეტაფიზიკური ხილვა აჩვენებს რეალობის დაფარულ, დრმა ფენას ქმნის განცდასა და გამოცდილებას, რომ რეალობა მეტია, ვიდრე ჩანს აღქმისა და ვიზუალური გამოსახულების დონეზე.

აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არ არის ტოტალურად ამორფული, როგორც წმინდა აბსტრაქცია; არც უშუალოდ ბუნებაში ან ხილულ რეალობაში დანახულის რეპრეზენტაციაა, როგორც რეალიზმი; არც სიზმრისეული და არაცნობიერიდან მომდინარე, როგორც სიურრეალიზმი. ამავე დროს, ის არ ქმნის მითურ ან ზღაპრულ ურჩხულებს, იმგვარად როგორც ჰიერონიმუს ბოსხი — მაგიური რეალიზმისა და სიურრეალიზმის ერთგვარი წინამორბედი. (Kuiper, K., October 8, 2025, Encyclopedia Britannica) ის არის ახალი არარეალური რეალობა, სადაც ხდება ხოლმე ობიექტების ჩანაცვლება მხატვრული ფორმებით მეტარეალისტური მხატვრული კომპოზიციის შექმნისას.

კითხვას აქ ასე დავაყენებდი: თუ ეს მიმდინარეობა არც აბსტრაქციაა, არც სრულად ფიგურატიული, არც სიურრეალიზმი, არც რეალიზმი; თუ მე, როგორც მხატვარი ამ განსხვავებას ვხედავ, როგორც სხვათა ნამუშევრებში, ისე თანამედროვე ხელოვნების პროცესებში და საკუთარ შემოქმედებაში — რა უშლის ხელს ამ მიმდინარეობის განვითარებას და მის ოფიციალურად ჩამოყალიბებას?

ტერმინი მეტარეალიზმი ზუსტად გამოხატავს იმ შემჩნეულ უხილავ-ხილულ “რეალობას”, რომელიც ერთი შეხედვით არარეალურია, თუმცა მხატვრის მეშვეობით ვლინდება. მე ვითვალისწინებ იმასაც, რომ მხატვრის შემოქმედება არის მდგრადი, ცვალებადი და განვითარებადი პროცესი; თუმცა საკუთარი ნამუშევრების დაკვირვებით და მათი შექმნისადმი მიდგომის ანალიზით, თვალსაჩინო ხდება, რომ აბსტრაქტულ-ფიგურატიული მეტარეალიზმი წარმოადგენს აზროვნების პატერნს. იქნება ეს ფერწერული ტილო თუ ინსტალაცია, თხზულება თუ პერფორმანსი, ეს პატერნი მუდმივად ვლინდება და თავს ავლენს “რეალობის” მრავალი შრის კომბინაციით.

აბსტრაქტულ-ფიგურატიული მეტარეალიზმი თავად წარმოადგენს მხატვრის პოზიციას, რომელიც განსაზღვრულია ქვემოთ წარდგენილი დეკლარაციით. დეკლარაცია ეყრდნობა ჩემ მიერ გამოქვეყნებულ ორ ინგლისურენოვან სტატიას „ახალი ხელოვნების მიმდინარეობის ანალიზი: აბსტრაქტულ-ფიგურატიული მეტარეალიზმი“ (გაიანე მანასიანი, 2024)[1], „აბსტრაქტულ-ფიგურატიული მეტარეალიზმის ხელოვნების დეკლარაცია“ (გაიანე მანასიანი, 2025)[2], აგრეთვე პრეზენტაციას „აბსტრაქტულ-ფიგურატიული მეტარეალიზმის ხელოვნების დეკლარაცია“, რომელიც ჩატარდა გიორგი ჩუბინაშვილის სახელობის ქართული ხელოვნების ისტორიისა და ძეგლთა დაცვის ეროვნულ კვლევით ცენტრში 2025 წლის 28 მაისს თბილისში.

1. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი მოიცავს რეალობის ხილულ და შესაძლო ტრანსფორმაციების ფართო დიაპაზონს. მხატვრული მიმდინარეობა ეფუძნება იმ პრინციპს, რომ რეალობა აღემატება მის ვიზუალურ გამოვლინებას. ხილული ფორმები მხოლოდ ნაწილია უფრო ფართო სისტემის. ერთის მხრივ, აქ იგულისხმება ისეთი განზომილებები, როგორიცაა დროითი პროცესები, ფსიქოლოგიური და ემოციური მდგომარეობები, სოციალური, კულტურული და პოლიტიკური სტრუქტურები; მეორეს მხრივ, მუდმივი ეგზისტენციალური განცდა კოსმოსში არსებობისა და მის მიღმა არსებული მოვლენების. ეს განზომილებები ურთიერთ კავშირშია და განაპირობებს ადამიანის ცნობიერების საზღვრებს — ან, უფრო ზუსტად, უსაზღვროობას.

2. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი ათავისუფლებს განსხვავებულ სურათებს; აბსტრაქციით არღვევს ფიგურატიული ხელოვნების საზღვრებს; ქმნის მეტაწერილებს. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არის კომპლექსური აზროვნების ვიზუალური გამოვლინება.

3. აბსტრაქტულ-ფიგურატიული მეტარეალისტი იკვლევს მარადისობასა და უსასრულო სამყაროს ზეცნობიერის თვალთახედვით, რომელიც აერთიანებს რეალობის აღქმას და რთული ჭეშმარიტების გაგების საშუალებას იძლევა. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 1)

4. აბსტრაქტულ-ფიგურატიულ მეტარეალისტს აინტერესებს ზეცნობიერი — ცნობიერების უმაღლესი დონე, რომელიც აღიქვამს მრავალ განზომილებას და ქმნის ამაღლებულ კათარზისულ ატმოსფეროს. ის ემსახურება შინაარსობრივად ზოგადსაკაცობრიო ზნეობრივი ნორმების წამოწევას. (გაიანე მანასიანი, 2024, გვ. 19, დებულება 2)

5. ის იკვლევს ხილულ რეალობას და ქმნის წარმოსახვით რეალობას, როგორც გამოხატვის საშუალებას, რომელიც არის მხატვრული. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 2)

6. აბსტრაქტულ-ფიგურატიული მეტარეალისტი ასახავს თავის ხედვას შესაძლო რეალობებზე დაყრდნობით და მათი ერთობლიობით. (გაიანე მანასიანი, 2024, გვ. 19, დებულება 3)

7. აბსტრაქტულ-ფიგურატიულ მეტარეალიზმში მთავარი სახელმძღვანელო არის ატმოსფეროს აღბეჭდვა. მრავალი რეალობის ერთიანობა და არა ოცნება ტილოზე. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არ იქმნება სიზმრების მეშვეობით ან რეალობის დამახინჯებით, არამედ ალტერნატიული რეალობის შესწავლით, „მრავალი“ რეალობების შეხამებით. (გაიანე მანასიანი, 2024, გვ. 19, დებულება 6)

8. წარმოსახვითი რეალობა ვლინდება და აღქმადია, როგორც კი ის უკავშირდება იმას ვისთვისაც არის შექმნილი ეს მეტაგზავნილი. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 3) ეს არის ის საკვანძო მომენტი, როდესაც მეტაწერილი იტვირთება განსაზღვრული შინაარსით; სხვა შემთხვევაში, მეტაგზავნილი შეიძლება ჩაითვალოს უშინაარსოდ.

9. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი აქტიურდება ხილული რეალობების განცდის და გააზრების მეშვეობით და ამ რეალობების გარდაქმნისა და განახლების გზით. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 4)

10. ის ეხება ცნობიერების მრავალ ფენას: არაცნობიერი, წინაცნობიერი, ცნობიერი და, რაც მთავარია, ზეცნობიერის ნაპერწკლები. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 5)

11. დროის მიღმა ყოფნა და თვით ყოფნა ეგოს დაკარგვასთან ერთად ირეკლება ტილოების სარკეებში, რომლებიც ზოგჯერ ფანჯრების, ზოგჯერ კი კარების ფუნქციას ასრულებენ. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 6)

12. აქ მთავარი ამოცანაა ამ რეალობის მიერ დათრგუნული „მე“-ს განთავისუფლება ზეცნობიერთან შეხების გზით. ზეცნობიერთან თანამშრომლობით, ასეთი ხელოვნება

მიზნად ისახას არა მხოლოდ საკუთარი მე-ს შემეცნებას — რომლის შესახებაც ადამიანმა პრაქტიკულად არაფერი იცის — არამედ მის შესწავლას უმაღლესი ცნობიერების დონეზე. (გაიანე მანასიანი, 2024, გვ.19, დებულება 7)

13. აღსანიშნავია, რომ როდესაც მხატვარი შემოქმედებით პროცესშია, აქ სიზმრისებური ხილვები არ არის საინტერესო მანამ, სანამ გონება არ გააანალიზებს ამ ქვეცნობიერს და დააკავშირებს მას რაღაც აღქმად და აღვილად გასაგებ იდეებთან ან მოვლენებთან. (გაიანე მანასიანი, 2024, გვ.19, დებულება 8) ზევცნობიერი გამოსახულება წარმოადგენს ამ კომპლექსური ანალიზის გამოცდილებას, რომელიც იძლევა მეტი მნიშვნელობის, სიღრმის და შინაარსის აღქმას.

14. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არ შეიძლება განიხილებოდეს მთლიანად, როგორც ფანჯარა არაცნობიერში — სადაც ლოგიკა მთლიანად უთმობს გზას ირაციონალურობას და ალოგიკურობას; უფრო სწორად ის არის ცნობიერების მიღმა და გაღმა. (გაიანე მანასიანი, 2024, გვ.19, დებულება 4)

15. გამოსახულების გამოხატვის სპონტანურობა დიდი დოზით არის წარმოდგენილი აბსტრაქტულ-ფიგურატიულ მეტარეალიზმში. ეს არის ეტაპი რომელიც ბუნებრივად მოჰყვება მედიტაციურ-ანალიტიკურ ეტაპს: რეალისტური ფენის გარდაქმნა ახალ რეალობად. მომენტი, როდესაც მასში, ხშირ შემთხვევაში, იბადება აბსტრაქცია. (გაიანე მანასიანი, 2024, გვ.19, დებულება 5)

16. აბსტრაქტულ-ფიგურატიული მეტარეალისტური გზავნილები არის კომპოზიციაში ფერების და ხაზების კოდირების ენა. (გაიანე მანასიანი, 2025, გვ.574, დებულება 7)

17. აბსტრაქტულ-ფიგურატიული მეტარეალისტური ნამუშევარი არის დიალოგი ტრანსფორმატიულ ძალასთან. ეს არის უხილავი რეალური სამყაროს მეტარეალური გამოსახვა. ფერი არის „სული“, რომელიც მოქმედებს როგორც დინამიკური მოძრაობა სივრცეში, რომელიც არის მარადიული და უსასრულო. (გაიანე მანასიანი, 2025, 574 დებულება 8)

18. აბსტრაქტულ-ფიგურატიულ მეტარეალისტურ სივრცეში სინათლე და სიბნელე თანაარსებობენ. მეტარეალისტი იყენებს ფერებს და იღუმალ სიბნელეს, რათა შექმნას აბსოლუტური ჰარმონია ჩრდილებისა და ხარვეზების უარყოფის გარეშე. მისი პროექცია ორგანიზებულია და ჰარმონიზებულია ქაოსში ზებუნებრივად. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 9)

19. ქარიშხლის შუაგულში ყოველთვის არის ბირთვი, რომელიც არის აბსოლუტური და „თვითცხადი“, ეს არის პერსპექტივა, რომელიც მას ნამდვილს ხდის. თხევადი და ქაოტური მოძრაობის ფონზე ბირთვი ფიქსირდება, და ის სტატიურია. (გაიანე მანასიანი, 2025, გვ.574, დებულება 10)

20. აბსტრაქტულ-ფიგურატიულ მეტარეალიზმს აქვს აბსტრაქციის გამორჩეული ელემენტი, რომელიც ინტუიტიური და სპონტანური კომპოზიციაში ფიგურატიულ გამოსახვასთან შედარებით. ეს ინტუიცია და სპონტანურობა თავად ქმნის ხელოვანთან ერთად. (გაიანე მანასიანი, 2025, გვ.574, დებულება 11)

21. ყველა ნახატი არის „თავსატეხის“ ნაწილი, რომელიც ქმნის უფრო დიდ სურათს. მრავალი რეალობის სახეობა გაერთიანებულია სხვა სამყაროს გამოსახულებებში, რომლებიც ამოცნობადია, მაგრამ ამავე დროს უცნობია. (გაიანე მანასიანი, 2025, გვ. 574, დებულება 12)

22. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი არ ითხოვს კონკრეტულ ცოდნას მის გასაგებად; პირიქით, ის სთავაზობს ტილოს გაშიფვრისას ცხოვრებისეული ცვლილებების გამოცდილებას. (გაიანე მანასიანი, 2025, გვ. 575 დებულება 13)

23. ბუნებასა და მის ელემენტებს კომპოზიციებში არა დეკორატიული, არამედ სტრუქტურული როლი აკისრიათ — ისინი განსაზღვრავენ ნამუშევრის განწყობას და ქმნიან მის ატმოსფერულ დინამიკას, ემოციურ და ვიზუალურ დაძაბულობას.

24. აბსტრაქტულ-ფიგურატიულ მეტარეალისტურ კომპოზიციებს თან ახლავს კონკრეტული მინიშნებები სათაურების სახით.

25. შემოქმედებითი პროცესი აღიქმება როგორც ცოდნის განვითარების საშუალება.

26. ხელოვნება განიხილება როგორც კვლევითი პრაქტიკა და არა მხოლოდ რეპრეზენტაცია.

27. აბსტრაქტულ-ფიგურატიული მეტარეალიზმი წარმოადგენს კომპლექსურ აზროვნებასა და ხედვას. (გაიანე მანასიანი, 2025, გვ. 575, 14 დებულება)

აბსტრაქტულ-ფიგურატიული მეტარეალიზმის სახასიათო თვისებებია რეალობის მრავალი დონის ერთობლიობა, სადაც თავისუფლდება ზეცნობიერი გამოსახულებები აბსტრაქციით და ჩართულია ცნობიერების დონეების კომპლექსური ანალიზი. აბსტრაქცია არღვევს ფიგურატიული ხელოვნების საზღვრებს და წარმოშობს მეტაწერილებს. (გაიანე მანასიანი, 2024, გვ. 16)

შეიძლება ითქვას მეტარეალიზმი ჩაისახა ოთხმოციან წლებში ჩემთან ერთად, განვითარდა და გამოვლინდა ჩემს შემოქმედებაში როგორც აბსტრაქტულ-ფიგურატიული მეტარეალიზმი — რაც მე გავაცნობიერე როგორც სამეცნიერო კვლევის, ისე მხატვრული პრაქტიკის შედეგად.

თვალსაჩინოების მიზნით, აქვე ვაქვეყნებ ჩემ მიერ შესრულებულ რამდენიმე აბსტრაქტულ-ფიგურატიულ მეტარეალისტურ კომპოზიციასა და ინსტალაციას.



„წერილები“ გაიანე მანასიანი

“The Letters” Gayané Manasyan

ტილო, ზეთი

Oil on Canvas

55.5 x 60.2 cm 2025



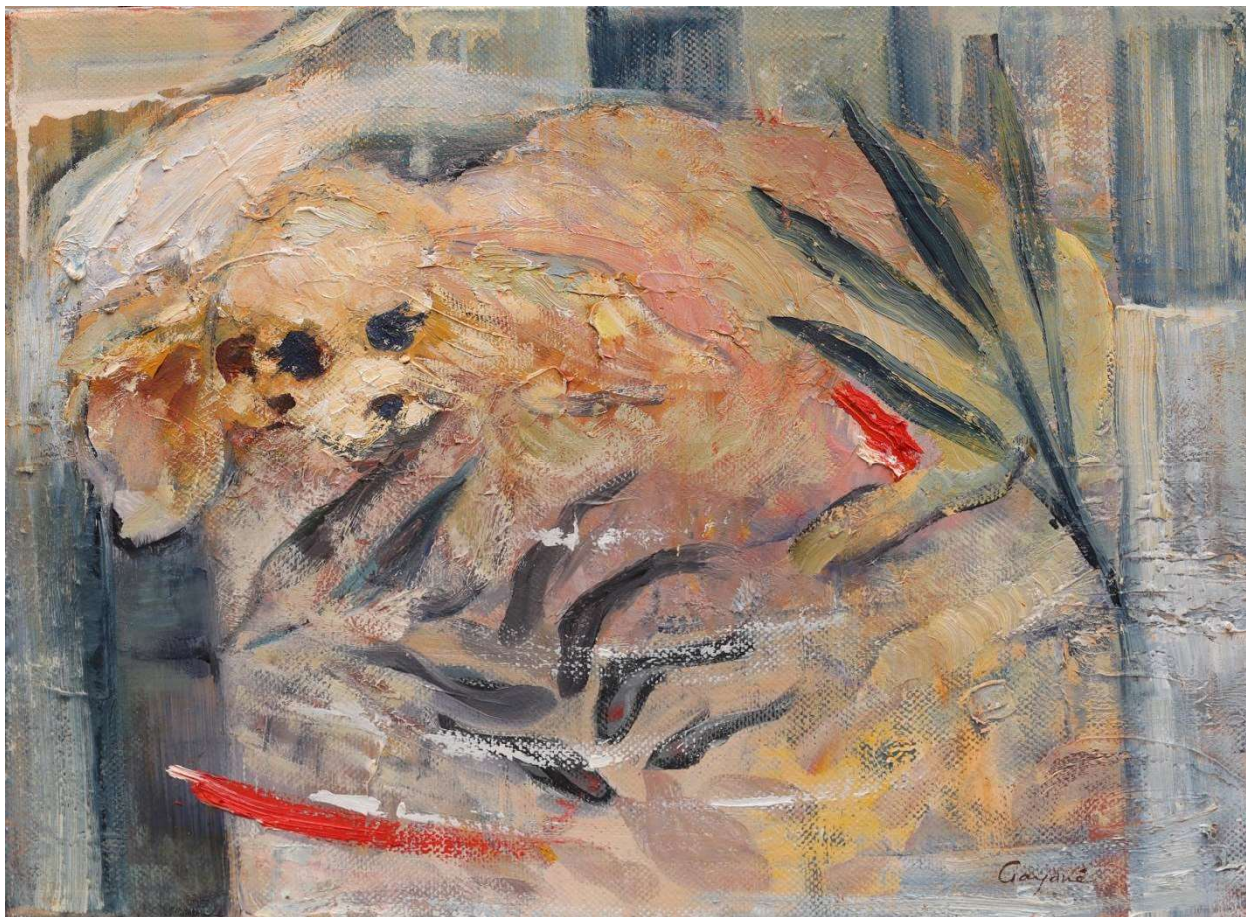
“გადასვლა და მეტამორფოზა” გაიანე მანასიანი

“Transition and Metamorphosis” Gayané Manasyan

ტილო, ზეთი

Oil on Canvas

128.5x102.2 cm 2025



„ნუცას ცუცა“ გაიანე მანასიანი

“Nutsa’s Tsutsa” Gayané Manasyan

ტილო, ზეთი

Oil on Canvas

35.4 x 48.3 cm 2024





In these photos **the Way** is installed in front of the Bauhouse; Nongyuan, Chengdu; Sichuan, China 2025 მოცემულ ფოტოში ნამუშევარი “გზა” ინსტალირებულია ბაუჰაუსის წინ; ნონგიუანი, ჩენგდუ; სიჩუანი, ჩინეთი, 2025.





The Way

Gayané Manasyan

H 170/W 788/D 130 cm

Mixed media (Mahjong tiles, metal, wood, recycled plastic, epoxy, bamboo, strong glue, hot glue, varnish, acrylic, gesso, oil color, spray paint.)

The Abstract-Figurative Metarealistic two-sided installation *The Way* is a path of personal transformation from earthly to heavenly, from ordinary to extraordinary, from consumption to spiritual. Modernized Chinese traditional elements, such as wooden carved calligraphy seal sculpture, mahjong tiles, floating clouds, yellow lotus flower, and bamboo, became a powerful part of Gayané's artistic vision: the object substitution, where objects deny their own identity, breaks logical expectations and creates materialistic meaning, and the artistic combination of Asian and European cultural codes.

Nongyuan Art Center, Chengdu; Sichuan, China 2025

„გზა“

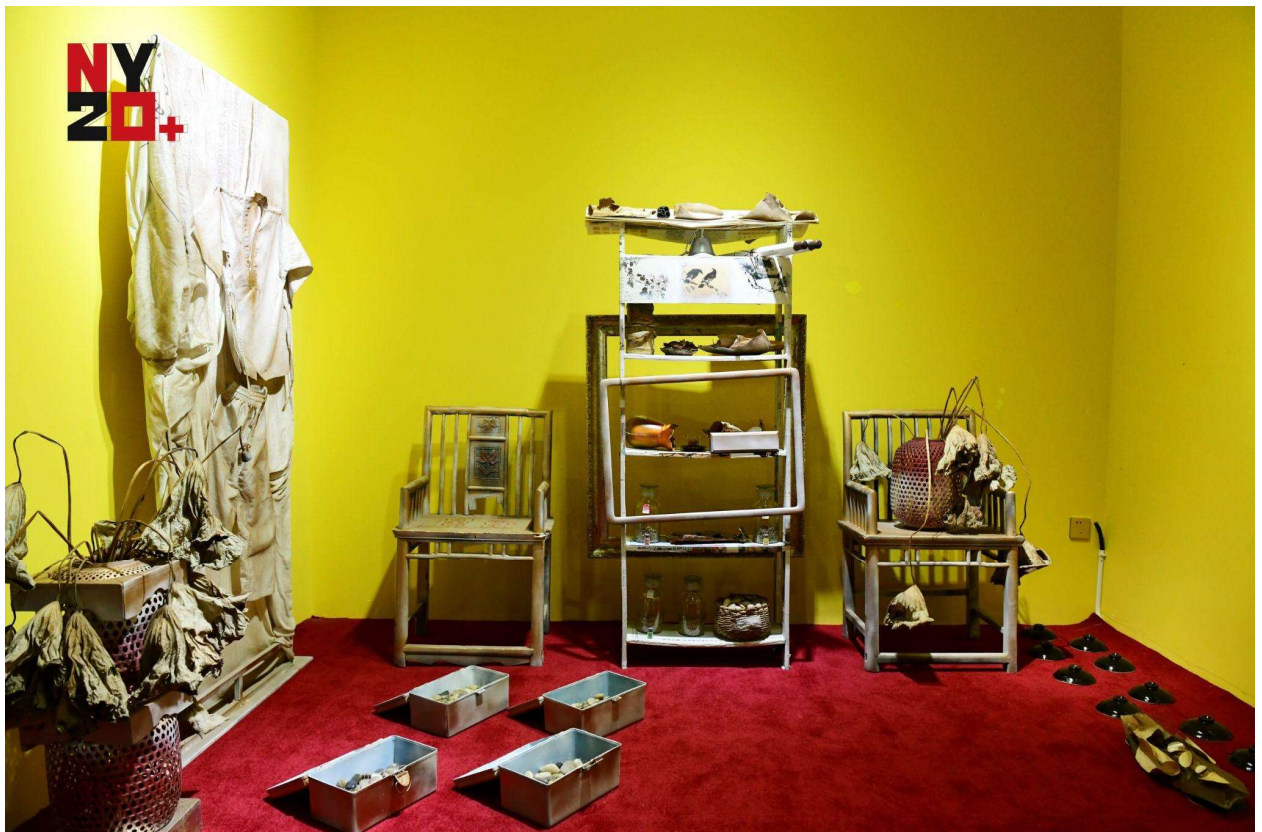
გაიანე მანასიანი

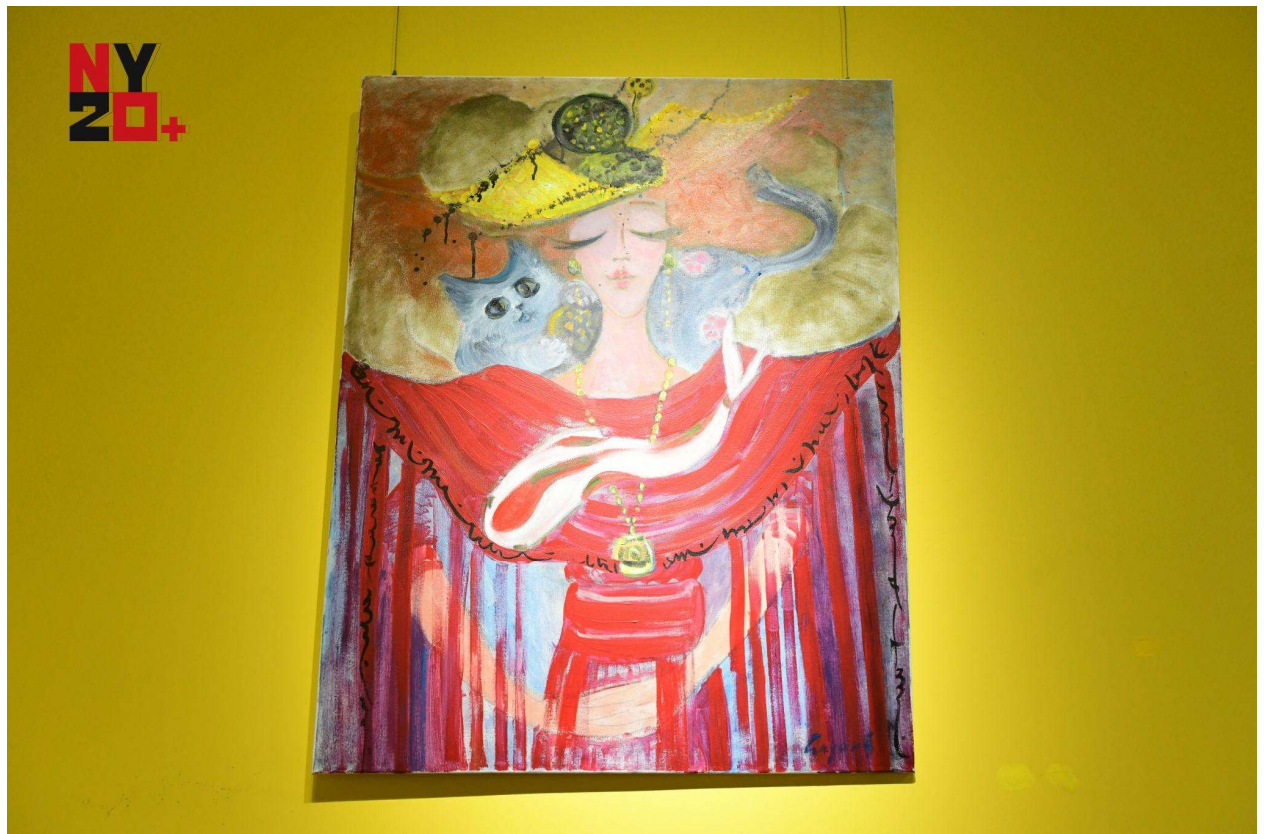
სიმაღლე 170 / სიგანე 788 / სიღრმე 130 სმ

შერეული მედია (მაჰჯონგის ფილები, მეტალი, ხე, გადამუშავებული პლასტიკი, ეპოქსიდი, ბამბუკი, ძლიერი წებო, ცხელი წებო, ლაქი, აკრილი, გესო, ზეთის საღებავი, სპრეის საღებავი).

აბსტრაქტულ-ფიგურატიული, მეტარეალისტური, ორმხრივი ინსტალაცია „გზა“ წარმოადგენს პირადი ტრანსფორმაციის მარშრუტს — მიწიერიდან ზეციურისკენ, ჩვეულებრივიდან არაჩვეულებრივისკენ, მოხმარებიდან სულიერისკენ. მოდერნიზებული ჩინური ტრადიციული ელემენტები, როგორიცაა ხეზე კვეთილი კალიგრაფიული ბეჭდის სკულპტურა, მაჰჯონგის ფილები, მცურავი ღრუბლები, ყვითელი ლოტოსის ყვავილი და ბამბუკი, გაიანეს მხატვრულ ხედვაში ძლიერ სიმბოლურ მნიშვნელობას იძენენ. ობიექტის სუბსტიტუცია — სადაც საგნები საკუთარ იდენტობას უარყოფენ — არღვევს ლოგიკურ მოლოდინებს და ქმნის მეტარეალისტურ მნიშვნელობებს, ხოლო აზიური და ევროპული კულტურული კოდების მხატვრული სინთეზი ნამუშევარს მრავალმრიან ინტერპრეტაციულ სივრცეს ანიჭებს.

ნონგუანის ხელოვნების ცენტრი, ჩენგდუ; სიჩუანი, ჩინეთი, 2025.





The Little Samurai and the Metarealistic Apothecary

Gayané Manasyan

H 200/W 428/D 70 cm

Mixed Media (Wood, fabric, iron, glass, newspaper, paper, natural materials such as dry lotus flower and leaves, bamboo shell, oyster shell, banana leaves, bark of the local trees, pebbles, hay, and seeds. Some plastic elements and recycled plastic. Oil paint, Chinese ink, and spray paint.)

The Abstract-Figurative Metarealistic installation is a temple for finding oneself in the chaos. It is the place of self-creation and healing. In the meditative state, The Lady in the Lotus Hat is facing the little Samurai. The asemic texts ornamenting her dress are metarealistic letters: the texts without meaning. The artwork supports the sacred atmosphere of gold, white, and red, with the color choice complementing the installation.

Nongyuan Art Museum, Chengdu, Sichuan, China, 2025

„პატარა სამურაი და მეტარეალისტური ალქიმიური ოთახი“

გაიანე მანასიანი

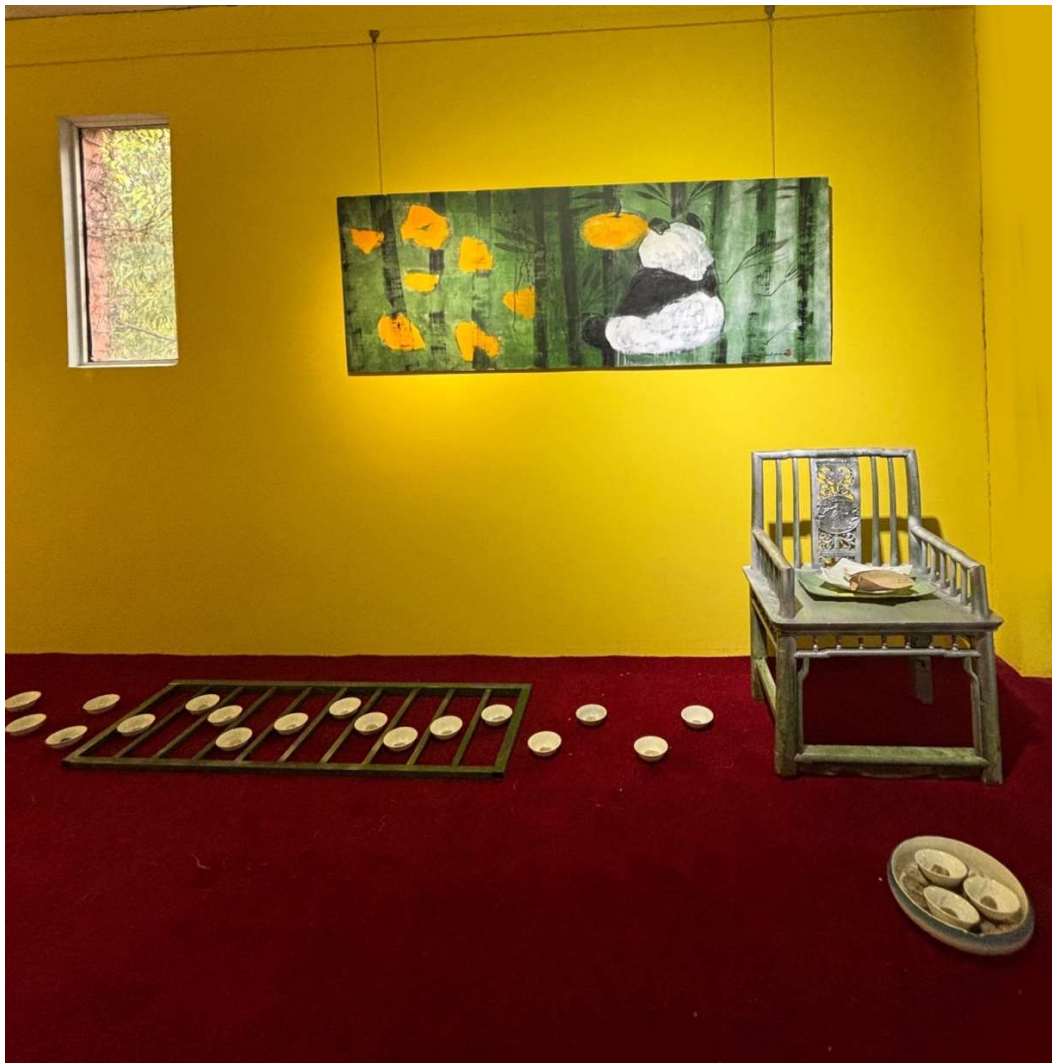
სიმაღლე 200 / სიგანე 428 / სიღრმე 70 სმ

შერეული მედია (ხე, ტექსტილი, რკინა, მინა, გაზეთი, ქაღალდი; ბუნებრივი მასალები, როგორიცაა გამხმარი ლოტოსის ყვავილი და ფოთლები, ბამბუკის გარსი, ნიჟარა,

ბანანის ფოთლები, ადგილობრივი ხეების ქერქი, კენჭები და თივა, თესლები, გადამუშავებული პლასტიკი, ზეთის საღებავი, ჩინური მელანი და სპრეის საღებავი).

აბსტრაქტულ-ფიგურატიული, მეტარეალისტური ინსტალაცია წარმოადგენს ტაძარს საკუთარი თავის პოვნისთვის ქაოსში — თვითშექმნისა და განკურნების ალქიმიურ სივრცეს. მედიტაციურ მდგომარეობაში მანდილოსანი გამოწყობილი ლოტოსის ქუდში პირისპირ დგას პატარა სამურაითან. მის კაბაზე გამოსახული ასეზიკური ტექსტები მეტარეალისტური ნიშნებია — ტექსტები მნიშვნელობის გარეშე. ფერთა შერჩევა — ოქროსფერი, თეთრი და წითელი — ქმნის და ამყარებს ნამუშევრის საკრალურ ატმოსფეროს, კომპოზიციის მთლიანობასთან ჰარმონიაში.

ნონგიუანის ხელოვნების მუზეუმი, ჩენგდუ, სიჩუანი, ჩინეთი, 2025.





The Tangerine Dream

Gayané Manasyan

H 151/W180/D70cm

Mixed Media (Wooden panel, acrylic, iron, wood, ceramics, pebbles, bamboo shell, oil and spray paint.)

The Abstract-Figurative Metarealist installation conveys the idea of unification into a harmonious self through embracing one's imperfections. The tangerine peel in the painting symbolizes the chaos and the process of self-discovery. The tangerine is a symbol of harmony, abundance, and energy. The bamboo forest and mist — the presence of mysterious emptiness. The idea evolves into artistic text on the bamboo shell on the ceramics. Pebbles in the bowls represent the imperfection of a person. The blue and white ceramic bowl is a symbol of the Lotus emerging from the water, awakening. The white and black ceramics stretch into a narrow path through the ladder-like forest, reminiscent of a cage. The colors of the installation, green and yellow, contribute to the idea that both the earth and heaven are a mystery.

Nongyuan Art Museum, Chengdu, Sichuan, China, 2025

„მანდარინისფერი ოცნება“

გაიანე მანასიანი

სიმაღლე 151 / სიგანე 180 / სიღრმე 70 სმ

შერეული მედია (ხის პანო, აკრილი, რკინა, ხე, კერამიკა, კენჭები, ბამბუკის გარსი, ზეთის საღებავი, სპრეის საღებავი)

აბსტრაქტულ-ფიგურატიული, მეტარეალისტური ინსტალაცია გამოხატავს იდეას ერთიანობისა ჰარმონიულ „მე“-ში საკუთარი ნაკლოვანებების მიღებით. ნახატში გამოსახული მანდარინის ქერქი განასახიერებს ქაოსს და საკუთარი თავის ძიების პროცესს. მანდარინი კი თავად არის ჰარმონიის, სიმდიდრისა და ენერგიის სიმბოლო. ბამბუკის ტყე და ნისლი აღნიშნავს მისტიკურ სიცარიელეს, რომელიც ინსტალაციაში გრძნობისა და სივრცის აღქმის ნაწილად იქცევა. იდეა ვითარდება ბამბუკის გარსზე

კერამიკაზე შესრულებულ მხატვრულ ტექსტში. ფიალებში განთავსებული კენჭები ასახავს ადამიანის ნაკლოვანებებს. თეთრი და ლურჯი კერამიკული თასი წარმოადგენს ლოტოსის წყლიდან ამომავლობას და გაღვიძებას. თეთრი და შავი კერამიკა განწყობილია კიბის ტყის გავლით შევიწროებულ გზად, რაც ასახავს ბარიერის. ინსტალაციის ფერები — მწვანე და ყვითელი — მიუთითებენ, რომ როგორც მიწა, ისე ზეცა, ერთსა და იმავე ხიბლსა და საიდუმლოს შეიცავს.

ნონგიუანის ხელოვნების მუზეუმი, ჩენგდუ, სიჩუანი, ჩინეთი, 2025.

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Political Studies

THE BALKAN REGION AS A GEOPOLITICAL SPACE

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Summary

This article presents an analysis of the Balkan region as a geopolitical space. The study aims to examine the historical, geographical, political, and economic characteristics of the region, as well as the interests of international actors. The Balkan Peninsula, located in southeastern Europe and bordered by the Black Sea, the Mediterranean Sea, and the Adriatic Sea, occupies a strategic position at the crossroads of major transit corridors. This location makes the region a focal point for both transportation and energy routes connecting Europe with Asia and the Middle East, as well as a site of competition among major powers. The article analyzes the geopolitical features of the Balkans, including its ethnic and religious diversity, energy and economic potential, and the challenges the region faces. Global and regional actors such as the European Union, NATO, Russia, Turkey, and China seek to advance their interests in the Balkans, increasing its strategic importance. At the same time, ethnic tensions, political fragmentation, and security risks remain key factors affecting regional stability. Both classical geopolitical theories (Mackinder, Spykman, Mahan) and contemporary approaches are addressed in the study. The future prospects of the Balkans are linked to regional cooperation, the development of energy projects, and political and economic reforms. The article is relevant not only for academic research but also for practical decision-making in international politics and security. In conclusion, the Balkan region remains a geopolitical space at the intersection of challenges and opportunities, and its analysis is essential for understanding both regional and global politics.

Keywords: Balkan region, Geopolitics, strategic position, International actors, energy and transit corridors, ethnic and religious diversity, regional security, Interests of global powers

Introduction.

Relevance of the article. The Balkan region, being one of the strategic centers of European and global politics, has significant geopolitical importance in both historical and contemporary contexts. Since the end of the 20th century, the Yugoslav conflicts, the Kosovo issue, ethnic and religious conflicts have caused the region to be permanently on the international agenda [Glenny.1999. 276]. In modern times, energy routes, transport corridors, the integration policies of NATO and the European Union, as well as the intervention of Russia, Turkey and China in the region, have further increased the strategic importance of the Balkans [Bechev 2019, 120].

The geopolitical position of the Balkans, its location on the transit corridors connecting Europe with Asia and the Middle East, the potential for controlling energy and trade routes, as well as its impact on regional stability and security issues, make the article relevant. At the same time, factors such as competition between global and regional actors, ethnic and religious diversity, economic development and democratic reforms necessitate an analysis of the region.

This article, by presenting an analysis of the Balkan region as a geopolitical space, serves as an important information base not only for academic researchers, but also for practical institutions dealing with international politics and security issues. Thus, the relevance of the topic is high in terms of the formation of strategic decisions and policies at both the regional and global

levels. In the system of international relations of the 21st century, the Balkan region comes to the fore as a special geopolitical space. Historically, the Balkan Peninsula, located at the crossroads of Europe, the Middle East and the Black Sea Basin, has always been in the spotlight in global politics due to its geographical location, as well as its political, ethnic and cultural diversity. This space has been shaped for centuries as a strategic area where the interests of empires, great powers and regional powers clash.

The concept of geopolitical space is primarily explained by the influence of geography on politics. Halford Mackinder's "Heartland" concept, Nicholas Spykman's "Rimland" theory, and Karl Haushofer's geopolitical views show that control over strategically located regions can play a decisive role in the global balance of power. The Balkans are characterized in these theoretical frameworks as both a "field of competition for control" and a "geopolitical laboratory of great powers."

The importance of the Balkan region in the modern era is due to several main factors. First, this space is located at the intersection of transport and transit routes connecting Europe with the Middle East and Asia. Second, the region has strategic potential in terms of energy routes and resources. Third, ethnic and religious diversity in the Balkans, as well as the risks of persistent conflict, occupy an important place on the international security agenda.

The geopolitical status of the Balkan region is also determined by the interests of great powers. The United States, the European Union, Russia, Turkey, and China are actively trying to influence the political and economic processes of this space. NATO expansion, the European Union's integration policy, Russia's historical and cultural ties, Turkey's regional influence, and China's "One Belt, One Road" initiative make the Balkans an important arena of competition and cooperation in international politics.

The purpose of the article. To analyze the Balkan region as a geopolitical space, to examine its geographical, political and economic characteristics, and to study the interests of regional and global powers. In addition, determining the security challenges and development prospects facing the region is of great importance in terms of understanding the future dynamics of international relations.

Methodology

This study is focused on the analysis of the Balkans as a geopolitical space and is based on analytical-synthetic, analysis of methods and systematic approaches. The scientific basis of the study is the classical and modern directions of international relations and geopolitics theories.

The first scientific-theoretical analysis was conducted, and the possibilities of applying Halford Mackinder's "Heartland", Nicholas Spykman's "Rimland" and Alfred Mahan's "sea power" concepts to the Balkan region were examined. The position of these approaches in the global balance of power in the region was determined.

The second economic-regional geopolitical analysis was conducted, and the close and different features of the Balkans in the Eurasian space with other strategies from the Caucasus, the East and Eastern Europe were determined. This method allows us to understand the geopolitical dynamics of the region and the mechanisms of influence of great powers.

The third program analyzed scientific research and statistical data on the policies of international organizations (EU, NATO), global actors such as Russia, Turkey and China by applying the empirical-analytical method.

As a result, the methodological approach is useful in the development of both classical geopolitical theories and modern international policy practices. This made it possible to conduct a multifaceted analysis of the Balkan region as a geopolitical space and scientifically substantiate its future prospects.

The concept of geopolitical space and theoretical approaches. Geopolitics, as one of the main directions of the science of international relations, studies the influence of geographical

factors on the foreign policy of states. In this regard, the concept of “geopolitical space” is defined as a territory of particular importance in global or regional politics due to the geographical position, natural resources, demographic structure and political environment of any region. In other words, geopolitical space is formed not only by physical-geographical borders, but also by the clash of political interests and the mutual influence of forces.

The classical foundations of geopolitical thought were laid at the end of the 19th and beginning of the 20th centuries. According to Halford Mackinder's "Heartland" theory, control of the center of the Eurasian continent is a crucial factor for global hegemony (Mackinder, 1904. 55.). Later, Nicholas Spykman put forward the concept of "Rimland", emphasizing that the coastal areas of the Eurasian continent, especially the Mediterranean, the Middle East and the Balkans, play an important role in the global balance of power [Spykman. 2007. 89].

Another direction of geopolitical theories is the concept of sea power. Alfred Mahan, showing that control over the seas is the main condition for global power, emphasized the importance of strategic water areas such as the Mediterranean and the Black Sea in international politics [Mahan. 2013, 78]. Karl Haushofer, as a representative of the German geopolitical school, developed the concept of “Lebensraum” and defended the fundamental factor of political power (Haushofer, 1924 .156). In the modern era, the concept of geopolitical space is not limited to military-strategic factors. In the context of globalization, energy routes, transit corridors, economic integration and information and communication technologies have also become the main parameters determining the geopolitical status of regions. In this regard, the analysis of the Balkan region should be carried out in the light of both classical geopolitical theories and modern approaches.

Main geopolitical frameworks and theoretical approaches in the modern era

1. Neorealist approach

Main idea: States seek to maintain their security and balance of power in the international system.

Representatives: Kenneth Waltz, John Mearsheimer.

Application area: Global power competition, military alliances, security issues.

For example: Russia-NATO relations, US-China competition.

2. Neoliberal geopolitics

Main idea: International cooperation, economic integration and organizations reduce interstate conflict.

Representatives: Robert Keohane, Joseph Nye.

Key concepts: Interdependence, “soft power”, the role of international institutions.

For example: the activities of the European Union, the UN, the World Trade Organization.

3. Contested (critical) geopolitics

Main idea: Geopolitics is based not only on geography, but also on discourse, ideology and media.

Representatives: Gearóid Ó Tuathail, Simon Dalby.

For example: The “West-East” division, the concept of “exporting democracy” – these are the products of political discourse.

4. “Clash of civilizations” (Samuel Huntington)

Main idea: In modern times, conflicts arise from cultural differences between civilizations, rather than ideology and economics.

For example: Conflicts between the West and the Islamic world, conflicts of cultural identity.

5. Neoregionalism

Main idea: Strengthening regional alliances against the backdrop of globalization.

For example: European Union, ASEAN, Organization of Turkic States, African Union.

Conclusion: Regional cooperation increases both economic and political stability.

6. Energy geopolitics

Main idea: Energy resources (oil, gas, energy lines) play a decisive role in the foreign policy of states and international relations.

For example: Zangezur corridor, "Southern Gas Corridor", competition for the Caspian region.

7. Other modern approaches

Ecological geopolitics: Climate change and resource allocation affect politics.

Technological geopolitics: Artificial intelligence, cybersecurity, information warfare.

Multipolar system approach: The world is no longer a system of one or two powers, but a system of multipolar power centers.

Geopolitical characteristics of the Balkan region. The Balkan Peninsula is located in the southeast of Europe and is distinguished by its access to the Black Sea, Adriatic Sea, Mediterranean Sea and Aegean Sea. The borders of the region are defined by the Danube River in the north, the Adriatic Sea in the west, the Mediterranean and Aegean Seas in the south, and the Black Sea in the east. Geographically, the Balkans play the role of a strategic bridge connecting Europe with the Asian and Middle Eastern regions. This position increases the geopolitical importance of the region and constantly brings it to the center of attention in global politics [Jelavich. 1983, 89].

One of the main elements of the geopolitical characteristics of the Balkans is its geographical location. Located on important transport and energy corridors in the East-West and North-South directions, the region acts as a place where the interests of the European Union, Russia, Turkey and the Middle Eastern states collide. In particular, the "Southern Gas Corridor", "TurkStream" and other energy projects have increased the transit potential of the Balkans [Kanli. 2019, 54].

The second important feature is ethnic and religious diversity. In this region, where Serbs, Albanians, Bosnians, Bulgarians, Romanians, Greeks and other peoples live side by side, the influence of Christianity (Orthodox and Catholic) and Islam is strong. These factors make the Balkans a fertile ground for both cultural richness and political conflict. The Yugoslav wars of the 20th century were one of the most striking manifestations of the geopolitical consequences of this diversity [Glenny.1999, 284].

The third main feature is the competition of great powers. Historically under the influence of the Ottoman, Austro-Hungarian and Russian empires, the Balkans are still a place where the geopolitical interests of the United States, the European Union, Russia, Turkey and China intersect in modern times. NATO enlargement and the integration policy of the European Union have led to the region's rapprochement with the West, but Russia and China have tried to create alternative mechanisms of influence on these processes [Bechev. 2019, 125].

The fourth important feature is security risks. The Kosovo issue, political fragmentation in Bosnia and Herzegovina, and historical disputes between North Macedonia and its neighbors are the main obstacles to stability in the region. These risks make the Balkans a priority not only on the regional but also on the international security agenda [Bieber.2018,15].

Thus, the geopolitical characteristics of the Balkan region are determined by its location at the strategic crossroads of Eurasia, its rich ethnic and religious mosaic, the clash of interests of great powers and persistent security problems. The combination of these factors turns the Balkans into a "geopolitical laboratory" in global politics.

Geographical position and natural resources. The Balkan Peninsula is located in the southeast of Europe and strategically plays the role of a bridge between the West and the East. The Danube River in the north, the Adriatic Sea in the west, the Mediterranean and Aegean Seas in the south, and the Black Sea in the east define the borders of the region [Jelaviich.1983,256]. This position allows the Balkans to act as an important geopolitical space in terms of transport,

energy, and military-strategic aspects. The natural resources of the Balkans also increase the importance of the region. In addition to steel, coal, bauxite, oil, and natural gas reserves, there is also a high agricultural potential. These resources attract the attention of regional and global actors and create opportunities for economic cooperation [Bechev.2019,54].

Transport-transit routes and strategic importance. The Balkans are located on the main transport and energy corridors connecting Europe with Asia and the Middle East. The “Southern Gas Corridor”, “TurkStream” and the Adriatic pipelines are of vital importance for the energy transit of the region [Kanlı.2019,60]. At the same time, the region has become a hub for logistical connections between the European Union countries and the Middle East, Turkey, and Russia via railways and highways. In this regard, the Balkans have both economic and political importance as a strategic transit hub.

Interests of regional powers. The Balkan region acts as a geopolitical space where the interests of great powers clash.

European Union (EU): Sees the region as an important part of its stability and integration policy, especially supporting the membership of the Western Balkan countries [Elbasany.2018,17].

NATO: Influences the security of the region through peacekeeping missions and the membership process, the membership of Albania, Croatia, North Macedonia and Montenegro is an example of this influence [Webber.2020,32].

Russia: Increases its influence in Serbia and Bosnia and Herzegovina through historical and cultural ties with Orthodox peoples, energy and political support .

Turkey: Expands its activity in the region through Ottoman heritage, cultural and economic ties, energy projects and diplomatic initiatives .

China: Strengthens its influence in the Balkans through economic and infrastructure projects under the “One Belt, One Road” initiative, especially in Serbia and Montenegro.

Thus, the Balkans remain a strategic space where both regional and global interests intersect. Geographical location, natural resources, transport corridors, and the interests of regional powers are the main factors increasing the geopolitical importance of this region.

Interests of international actors. The Balkan region is not only an internal issue of Europe, but also a place where the strategic interests of global powers clash. Both regional and global actors exert influence and compete.

The European Union (EU) is one of the most active actors in the Balkans. Seeing the region as an important part of the European security architecture, the EU aims to integrate the Western Balkan countries into the organization in the long term. This approach is aimed at both maintaining stability and promoting economic development. However, enlargement fatigue within the EU and resistance from some states are slowing this process [Elbasany.2018,14].

NATO also plays a key role in the security system of the region. Peacekeeping missions carried out in the Balkans after the Yugoslav wars and the subsequent membership process have increased NATO's influence in the region. Currently, Albania, Croatia, North Macedonia and Montenegro are NATO members. This process creates tension between neutral countries such as Serbia and Bosnia and Herzegovina and Western structures.

Russia sees the Balkan region as part of its historical and cultural sphere of influence. Historical ties with Orthodox Christian nations, energy dependence, and political support are Moscow's main tools of influence. Russia is particularly trying to maintain its political influence in Serbia and Bosnia and Herzegovina. At the same time, Russia's strategic balancing policy towards Europe is more pronounced in the Balkans [Aydın-Düzgit.2019,18].

Turkey is also an important regional actor that is increasingly active in the Balkans. It is expanding its influence through its Ottoman heritage, cultural affinity, economic ties, and religious institutions. Ankara is also trying to strengthen its position in the region with energy projects, transport corridors, and diplomatic initiatives.

China has entered the Balkan region in recent years through economic and infrastructure projects within the framework of the “One Belt, One Road” initiative. Chinese investments are particularly noticeable in Serbia, Montenegro, and Bosnia and Herzegovina. Beijing’s main interest is to access European markets and turn the region into a logistics hub [Tonchey.2020,6].

Thus, the Balkans remain a place where the interests of great powers intersect in international politics. The integration policy of Western structures, Russia’s attempts to create a balance, Turkey’s cultural and political activity, and China’s economic expansion are turning this region into an area of multipolar competition.

Challenges and perspectives.

Although the Balkan region is of strategic importance from a geopolitical perspective, it faces a number of challenges. These challenges affect both regional stability and the interests of global actors.

The first challenge is the tension arising from ethnic and religious diversity. The coexistence of Serbs, Albanians, Bosniaks, Bulgarians, Romanians, Greeks and other peoples creates a rich cultural environment and increases the risk of conflict. The Kosovo issue, political divisions in Bosnia and Herzegovina and other ethnic disputes constantly threaten the security of the region [Mahan.2013,78].

The second challenge is related to energy and transit corridors. The Balkans are of strategic importance in terms of gas and oil routes to Europe. However, the protection of these corridors, energy dependence and competition create political tension in the region. In particular, the “Southern Gas Corridor”, “TurkStream” and other projects clash the interests of international actors [Macinder.1962,56].

The third challenge is the balance problems arising from the competition of great powers. The integration policies of NATO and the European Union, Russia’s attempts at influence, and the economic expansion of Turkey and China complicate the geopolitical balance in the Balkans. This increases uncertainty in the strategic decisions of regional actors [Bechey.2019,122].

The geopolitical prospects of the Balkans are associated with a number of opportunities. The region’s integration into Europe, the development of infrastructure and energy projects, regional cooperation initiatives and cultural diplomacy can serve to increase stability. In addition, economic and political reforms, the fight against corruption and the strengthening of democracy increase the potential of the Balkans to become one of the strategic and economic centers of Europe [Elbasany.2018,16].

Thus, the Balkan region remains an important space for global and regional politics in terms of both challenges and prospects. Its geopolitical role will be crucial in the strategies of both European and global actors in the future.

In addition to its strategic importance from a geopolitical perspective, the Balkan region faces a number of challenges and prospects. These factors affect both regional stability and the interests of international actors

1. Security risks

Ethnic and religious diversity, historical conflicts and political fragmentation in the Balkans constitute the main security risks of the region. The Kosovo issue, ethnic conflicts in Bosnia and Herzegovina and tensions between North Macedonia and neighboring countries are examples of these risks [Bieber.2018,14]. Conflicts, border disputes and internal political instability pose potential threats to both regional and global security.

2. Energy and economic projects

The strategic location of the region is favorable for energy and economic projects. The “Southern Gas Corridor”, “TurkStream”, Adriatic pipelines and railway projects allow the Balkans to become an energy transit and trade hub [Kanli.2019,57]. At the same time, economic cooperation,

infrastructure projects and foreign investments strengthen the stability and development prospects of the region.

3. Future development scenarios

The future prospects of the Balkans are related to several scenarios:

European integration: The integration of the Western Balkan countries with the EU and NATO can enhance political stability and economic development.

Regional cooperation: SEECP (**South-East European Cooperation Process**), RCC(**Regional Cooperation Council**) and other regional initiatives can reduce the risks of conflict by increasing economic and security cooperation [Elbasany.2018,15].

Influence of global powers: The competition between the US, Russia, China and Turkey will determine the geopolitical balance of the region, creating both challenges and opportunities for cooperation.

Thus, the Balkan region remains a strategic space where both challenges and opportunities intersect. Its future development will depend on security, energy and economic projects, as well as the interests of regional and global actors.

Conclusion

The Balkan region is one of the strategic centers of Europe and global politics from a geopolitical perspective. Historical experience, geographical position, ethno-religious diversity and energy routes are the main factors increasing the geopolitical importance of the region. Classical and modern geopolitical theories confirm that this region plays a decisive role both in the Eurasian continent and in the global balance of power. The Balkan region remains a place of strategic importance in international politics. Its geographical position, natural resources, energy and transport corridors make the region a center where the interests of global and regional actors intersect. The geopolitical features of the Balkans and the challenges related to security risks increase the role of the region in international politics.

The interests of regional and global actors in the Balkans overlap, creating complex mechanisms of influence. While the European Union and NATO pursue a policy of integration and stability, Russia, Turkey and China seek to protect and expand their spheres of influence. This competition creates both challenges and opportunities for cooperation.

Regional and global powers the European Union, NATO, the United States, Russia, China and Turkey are trying to maintain and expand their spheres of influence in the Balkans. At the same time, SEECP (**South-East European Cooperation Process**), RCC (**Regional Cooperation Council**) and other regional organizations are trying to ensure stability by strengthening cooperation. This situation turns the Balkans into a strategic space where both challenges and opportunities for cooperation intersect.

From a geopolitical perspective, the future of the Balkans is connected with a number of factors: political and economic reforms, management of ethnic and religious conflicts, development of energy and infrastructure projects and strengthening regional cooperation. These factors will determine the stability and development of the region, as well as influence the formation of global and regional policies.

The future prospects of the region are connected with a number of factors. Ensuring political stability, developing economic infrastructure projects, strengthening energy security and regional cooperation initiatives can turn the Balkans into one of the strategic and economic centers of Europe. On the other hand, ethnic and religious contradictions, historical disputes and competition between global powers still make risks relevant.

Thus, the Balkan region remains a geopolitical space where both challenges and opportunities collide. Its analysis is of great importance not only for regional politics, but also for the formation of global strategies. This article has attempted to shed light on future prospects by summarizing the geopolitical characteristics of the Balkans, the interests of international actors

and the challenges facing the region. As a result, the Balkan region remains an important space for understanding international politics and geopolitical strategies, and its analysis is of great importance both from an academic and practical point of view.

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Biological Sciences

РАЗРАБОТКА И ПЕРСПЕКТИВЫ КОММЕРЦИАЛИЗАЦИИ БИОЛОГИЧЕСКОГО ПРЕПАРАТА «АНТИМОСКИТ» НА ОСНОВЕ *BACILLUS* *THURINGIENSIS ISRAELENIS* ДЛЯ БОРЬБЫ С КРОВОСОСУЩИМИ НАСЕКОМЫМИ

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Введение. Рост численности популяций кровососущих двукрылых насекомых (гноса), включая комаров и мошек, представляет собой значительную санитарно-эпидемиологическую и социально-экономическую проблему в Казахстане и других регионах со схожими климатическими условиями. Эти насекомые являются переносчиками опасных заболеваний, таких как малярия, филяриоз, лихорадка Западного Нила, а также причиняют серьезный дискомфорт населению и снижают продуктивность сельскохозяйственных животных [1, 4]. Традиционные химические инсектициды, ввиду развития резистентности у насекомых, высокой токсичности для окружающей среды и накопления в экосистемах, перестают быть эффективным и безопасным решением [4]. Особую сложность представляет обработка водоёмов, где применение химических средств запрещено.

В этом контексте разработка и внедрение экологически безопасных биологических препаратов приобретает стратегическое значение. Мировым стандартом биологической борьбы с личинками комаров и мошек являются препараты на основе бактерии *Bacillus thuringiensis* var. *israelensis* (Bti), действие которых основано на белковых эндотоксинах, избирательно поражающих пищеварительную систему личинок двукрылых [2, 5, 9]. Актуальность настоящего исследования обусловлена острой необходимостью создания собственного, доступного и эффективного отечественного биопрепарата для Казахстана, что позволит снизить зависимость от импорта, обеспечить стабильные поставки и существенно удешевить профилактические мероприятия.

Методология исследования

Объектом исследований являлся биологический препарат «Антимоскит» в форме порошка, представляющий собой спорокристаллический комплекс штамма *Bacillus thuringiensis* var. *israelensis* с массовой долей активного комплекса 90% [6, 7]. Препарат производится по энергоэффективной ферментационной технологии на основе отечественного сырья. Действие препарата основано на кишечном механизме: личинки, поглощая споры и кристаллические включения, погибают вследствие поражения эпителия кишечника специфическими Cry- и Cyt-токсинами (Cry4Aa, Cry4Ba, Cry11Aa, Cyt1Aa) [2, 5].

Полевые испытания были проведены на участке реки Нура в Карагандинской области (протяженность 11 км) с целью оценки ларвицидной активности в естественных условиях. Нормы расхода препарата рассчитывались в зависимости от ширины русла (10–400 м), скорости течения (1–8 км/ч) и степени загрязненности воды, что отражено в разработанных технологических таблицах [Отчет]. Рабочая суспензия готовилась концентрацией 1,5%, норма внесения составила 1,5 кг/га. Оценка эффективности проводилась путем отбора проб воды и учета гибели личинок через 6, 9, 12 и 48 часов после обработки. Дополнительно контролировалось состояние сопутствующей фауны (рыбы, беспозвоночные).

Результаты и обсуждение

Проведенные испытания продемонстрировали высокую эффективность биопрепарата «Антимоскит». Через 6 часов после обработки наблюдалась гибель 74–77% личинок мошки, а оставшиеся особи были малоподвижны. Через 9 часов экспозиции в исследуемом участке была зафиксирована 100%-ная гибель личинок, а через 12 часов не обнаружено ни личинок, ни куколок. Важнейшим результатом является отсутствие негативного воздействия на сопутствующую фауну на протяжении всего периода наблюдений, что подтверждает высокую селективность и экологическую безопасность препарата.

Эффективность препарата подтверждена в отношении широкого спектра целевых объектов: личинок комаров семейства Culicidae, включая роды Culex и малярийных комаров Anopheles stephensi, а также личинок мошек семейства Simuliidae. Испытанный штамм Bti показал высокую активность, соответствующую мировым аналогам [5, 7, 9]. Препарат также характеризуется относительно высокой стабильностью при хранении в условиях повышенных температур, что упрощает логистику и расширяет возможности применения в различных климатических зонах.

Технико-экономические показатели препарата делают его конкурентоспособным решением: при норме расхода 1,0–1,5 кг/га обеспечивается ларвицидная эффективность до 95–100% в водоёмах. Использование отечественного сырья и энергоэффективной технологии ферментации позволяет минимизировать себестоимость производства.

Заключение и выводы

Разработка и успешные испытания биопрепарата «Антимоскит» представляют собой значимый результат, имеющий выраженную практическую значимость для бизнеса, государственного управления и экологии. Препарат эффективно решает комплекс проблем, связанных с массовым распространением гнуса, предлагая научно обоснованную, безопасную и экономически выгодную альтернативу химическим средствам.

Практическая значимость и бизнес-перспективы заключаются в следующем:

1. **Закрытие рыночного дефицита:** Создание отечественного производства позволит обеспечить стабильные поставки эффективного ларвицида для нужд санитарно-эпидемиологических служб, акиматов, природоохранных организаций и агропромышленного комплекса, снизив зависимость от дорогостоящего и нерегулярного импорта.
2. **Широкий рынок сбыта:** Область применения препарата охватывает высокочувствительные секторы: природоохранные зоны (национальные парки, заповедники), детские и рекреационные учреждения (лагеря, базы отдыха), сельское и приусадебное хозяйство, коммунальное хозяйство населенных пунктов, расположенных вблизи водоемов.
3. **Конкурентные преимущества:** Ключевыми преимуществами «Антимоскита» являются доказанная экологическая безопасность для гидробионтов, теплокровных животных и человека, отсутствие резистентности у целевых насекомых за десятилетия мирового

применения Bti [5, 9], а также возможность безопасного применения в проточных и стоячих водоёмах, где химические инсектициды запрещены.

4. Экономическая эффективность: Локальное производство на основе отечественной ресурсной базы и энергоэффективных технологий обеспечит низкую себестоимость, что сделает масштабные обработки территорий финансово доступными для бюджетных и коммерческих организаций.

5. Инновационный и экспортный потенциал: Препарат защищен патентами Республики Казахстан (патент на изобретение №2020/0116.1, патент на полезную модель № 11130), что формирует основу для развития высокотехнологичного производства и потенциального выхода на рынки других стран Центральной Азии, сталкивающихся с аналогичными проблемами.

Таким образом, внедрение биопрепарата «Антимоскит» не только вносит вклад в улучшение санитарно-эпидемиологической обстановки и качества жизни населения, но и формирует новое конкурентоспособное направление в биотехнологической промышленности Казахстана. Реализация данного проекта соответствует принципам «зеленой» экономики, обеспечивая баланс между эффективной борьбой с вредителями и сохранением экосистем.

Статья подготовлена по результатам научного исследования в рамках инициативной темы «Проведение полевых испытаний и изучение эффективности биологического дезинфекционного (инсектицидного) средства «Антимоскит» на основе *Bacillus thuringiensis* var. *israelensis*» (Пер. № 0125РКД0148).

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