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4 BUILDING THE FUTURE THROUGH STEM EDUCATION: A CATALYST FOR SUSTAINABLE DEVELOPMENT AND NATIONAL REVIVAL OF UKRAINE

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ABSTRACT

This section of the monograph highlights the role of STEM education in the context of achieving the Sustainable Development Goals and their impact on the national revival of Ukraine. Methods of integration of STEM education to help solve global challenges are analyzed. Thanks to a carefully planned research, conducted among teachers and future teachers of various specialties of Berdyansk State Pedagogical University, the work analyzed the different views of the interviewees on the key STEM skills necessary to achieve the SDGs and their practical application in real conditions. According to the results of the study, special attention was paid to the importance of technological skills and literacy, critical and problem-solving thinking, creativity, communication skills, as well as the ability for pedagogical innovations and interdisciplinary integration.

In addition, the chapter of the monograph emphasizes the decisive role of higher education institutions in promoting sustainable development through strengthening their social responsibility and partnership with other stakeholders. The research findings point to the need to update educational programs and teaching methods in accordance with the requirements of the modern world, with the aim of training future teachers of various specialties who are able to contribute to solving global challenges to achieve the Sustainable Development Goals. The author's team offers strategic recommendations regarding the integration of STEM education and the SDGs at the level of higher education institutions in order to train highly qualified specialists capable of contributing to the sustainable development of society in Ukraine and the world. The results of the study become especially relevant in the context of the ongoing war in Ukraine and its post-war recovery, emphasizing the need for quick and balanced steps to adapt the educational system to modern challenges. Emphasizing the importance of STEM education for national revitalization and sustainable development, the research encourages discussions and practical actions among educators, scientists, state authorities, and representatives of business and industry. It becomes a call for the necessary changes in education, aimed at the formation of a new generation of specialists capable of offering solutions to society's problems by combining natural sciences, technology, engineering and mathematics, and contributing to the restoration of Ukraine as a strong, independent and innovative state.

KEYWORDS

STEM education, sustainable development, Sustainable Development Goals, STEM skills, higher education, universities, interdisciplinary approach, creative thinking, critical thinking.

4.1 INTRODUCTION

Science plays a key role in the development of mankind, affecting all aspects of our lives: from technology and medicine to social systems. History shows that scientific discoveries and technological progress have not only contributed to the expansion of our knowledge about the world, but also transformed our daily existence. Inventions, such as tools, wheel, electricity, computers, medicines and others, not only have made our lives more comfortable, but also influenced its meaning from native survival to the philosophy of well-being [1]. Science has proven to be a powerful force that helps our civilization to ensure sustainable development for future generations.

Now, against the backdrop of global challenges, STEM can be not only a progressive educational and scientific approach, but also a catalyst for solving large-scale problems of humanity. In this chapter, we will look at the importance of STEM education in the context of achieving the sustainable development goals (hereinafter referred to as SDGs) and highlight how this approach contributes to the development of important skills in modern youth, which will become their tools for building a better future.

In the sense of Abul-Nasr & Mohamed, the SDGs are a benchmark for modernization of society in the context of its transition from the current state to the best [2]. And it is the reform of education that is determined by the key tool for achieving all other goals through the development of relevant curricula and educational materials, teacher preparation and upgrade of the educational environment [3]. Because this sector provides further employment, helps to develop life skills and, most importantly, improves youth development [4].

Today, global challenges, such as climate change, environmental protection, digital transformation and social changes, require a comprehensive innovative approach to solve them [5]. Therefore, the focus is experts who have a wide range of knowledge and STEM skills, which allow them to solve complex research tasks in various fields.

Scientists' opinions on STEM education prospects are different to achieve the SDGs. There are studies that have proven that the STEM approach is effective for achieving the SDGs in the field of education and environmental development, but for humanitarian purposes (overcoming hunger and poverty) it is not so effective [6]. Others argue that STEM cannot be considered solely as a tool for achieving economic and technocapitalistic goals in global competition. Finally, it is necessary to take into account the STEM potential to achieve the SDGs of socio-cultural and axiological orientation [7, 8].

The SDG focus in STEM education is one way to expand the horizon of students, involving them in problems that can be crucial to the whole world [9]. In particular, through the development of their creative and systemic thinking [10]; work on tasks on the basis of an interdisciplinary approach [11, 12]; understanding of the risks of technophilia (belief that everything can be solved with technology) [13]; promotion of initiatives to overcome gender stereotypes in science [14] and others.

In the current discourse, higher education institutions (hereinafter referred to as the HEIs) play a crucial role [15]. They bear "social responsibility" to the academic community, not only contribute to the training of qualified professionals who are able to make their contribution to economic

growth and social progress, but also cultivate in them conscious attitude to world problems, such as climate change, poverty, inequality and loss of biodiversity [16]. Universities, according to Leal Filho et al., affect local communities, serving models of sustainable development and providing a socio-economic contribution to the host communities through graduates working in the local region, or creating live laboratories in cooperation with interested parties in their communities [17].

Recognizing the importance of social responsibility and their impact at the local level, HEIs also deploy their efforts to effectively cooperate with other interested parties. Such partnership is based on the search for ways to achieve the SDGs, promote innovations in the local context, exchange expert knowledge and resources, promote the problem of modernization of educational practices on the basis of STEM, in particular among non-STEM students [18]. Thanks to the active experience in higher education institutions on the basis of STEM, the scientific literacy of teachers is increasing, which, in turn, will improve their contribution – both personal and professional – to achieve the SDGs, in particular through the promotion of this policy in schools [19].

However, if we introduce high quality education that provides students with the skills, required to achieve the SDGs, then integration of SDG content in STEM education using humanitarian and social sciences is essential. This will allow students to openly look for links between the challenges of global development and local realities, their own life and career [20]. The idea of such laboratory universities ("live laboratories") for the implementation of the SDGs with the help of STEM is not new and is effectively implemented [21]. It is especially relevant for pedagogical universities, because it is teachers who can promote SDG ideas and instill appropriate values to new generations of children [22].

It is critical for Ukraine, given the specific difficulties, faced by the country due to the ongoing war, the need for post-war recovery and partial loss of academic potential of universities [23–26].

Therefore, the implementation of STEM education is the basis for implementing a strategy for sustainable economic development and society. This educational innovation will prepare an educated youth capable of working productively to achieve the SDGs. They will produce innovative solutions, provide technological progress, promote natural and mathematical education, results of their inventive and scientific-oriented activities. In this way, their rights and opportunities will expand, becoming the foundation to increase national sustainability.

However, the successful implementation of such a scenario depends on several key factors. Among them is a special place of advanced training of the teachers of HEIs, who are the starting link of professional training of future specialists [27]. It is largely dependent on their competence to how effectively young people will be able to master the appropriate STEM skills to achieve the SDGs. Meanwhile, students' self-awareness of STEM skills and their motivation to acquire these skills also play a critical role in this process. Their active position on this issue will not only contribute to a deeper learning of the material, but also allow you to express thoughts, produce creative ideas and offer ways to use scientific knowledge and skills to solve global challenges. Such bilateral interaction between teachers and students creates the basis for the development of an innovative and responsible approach to learning, which leads to the formation of a solid basis for future development and prosperity of society in the conditions of sustainable development.

Taking into account the above, the purpose of the scientific work is to research and analyze the role of STEM education in achieving the SDGs and its impact on the national revival of Ukraine. It focuses on the identification of key STEM skills, needed by future teachers of various specialties to effectively address modern challenges, as well as on the identification of strategies for the effective integration of the SDGs into STEM education. In accordance with the purpose of the research, the following tasks are defined: studying the perception of the importance of STEM skills among students and teachers of various specialties; deepening the understanding of how exactly students see the application of STEM skills to achieve the SDGs in real-world settings through the analysis of concrete examples and scenarios; development of strategic recommendations regarding the integration of STEM education and the SDGs at the level of higher education institutions, with the aim of training highly qualified specialists capable of contributing to the sustainable development of society in Ukraine and the world.

4.2 RESEARCH METHODOLOGY

The study was conducted at Berdyansk State Pedagogical University (Berdyansk, Ukraine). Due to the temporary occupation of the city, Berdyansk State Pedagogical University changed its location and was moved to the city of Zaporizhzhia. According to this, the educational process in the HEI is now carried out using distance learning technologies until the situation in the country stabilizes.

As part of this study, the questionnaire method was used to collect information from teachers and future teachers of various specialties of Berdyansk State Pedagogical University. This approach made it possible to obtain answers to questions related to the assessment of the importance of STEM skills in the context of their impact on the effective implementation of STEM education in professional activities and their contribution to the achievement of the SDGs. In particular, the main attention was paid to the analysis of differences and similarities in determining priorities in order to further develop strategic recommendations for the integration of STEM education and the SDGs at the level of HEI.

4.2.1 DEVELOPMENT OF THE QUESTIONNAIRE

The main tool was two author questionnaires: for university teachers and for students. Each was created taking into account the analysis of available scientific research and legal documents that determine the regulatory and legal basis for the implementation and development of science and mathematics education, the achievement of the SDGs in the world and in Ukraine.

The questionnaires contained a variety of question types, including general questions about the respondents, as well as those that allowed them to express their thoughts and ideas in more detail to provide a deeper understanding of their beliefs and perceptions.

The questionnaires were presented for evaluation by a group of qualified experts in the field of education. After a careful analysis and peer-reviewed corrections, it was ensured that both questionnaires contained questions that comprehensively covered various aspects of the research topic. This approach made it possible to guarantee a complete and multifaceted understanding of it. The experts also focused on optimizing the length of the questionnaires to minimize the risk of respondent fatigue and potential decline in the quality of their responses, while ensuring a high level of respondent engagement. In addition, measures were taken to ensure that the content of the questionnaire adequately reflects the key concepts and notions under study, as well as meets the stated purpose and objectives of the study. This involved a detailed validation of the questions to avoid misunderstandings and increase the accuracy of the data collected.

The experts made important adjustments to some questions, making them more understandable for the participants, removing ambiguity and bias that could affect the quality of the work done. Thanks to these efforts, the questionnaire was optimized to effectively collect the information necessary to analyze the impact of STEM education on the achievement of the SDGs and its role in the national revitalization of Ukraine, while ensuring clarity and comprehensibility for all research participants.

4.2.2 ADMINISTRATION OF THE QUESTIONNAIRE

The administration of the questionnaires was carried out using the Google Forms service, which made it possible to efficiently and quickly attract a wide range of participants. Electronic questionnaires were initially sent to the corporate e-mail addresses of the deans of the faculties, who further facilitated their distribution among the academic staff and the student community, involved in the questionnaire process.

This approach ensured that all respondents, without exception, had the opportunity to participate in the survey, contributing to the optimization of data collection through the active use of corporate e-mail as the main means of communication in the university. The use of digital tools helped to overcome the territorial and time constraints, associated with the forced displacement of the academic community due to the military conflict in Ukraine, allowing respondents from different regions of the country and beyond to actively participate in the research. This, in turn, is critically important for ensuring high quality and reliability of the received data.

4.2.3 DEMOGRAPHICS OF THE PARTICIPANTS

182 teachers and 664 students of various specialties of Berdyansk State Pedagogical University took part in the study. This number of participants formed a representative sample that reflects a diversity of opinions and perspectives, which is key to providing an objective and

comprehensive analysis of the impact of STEM education on the achievement of the SDGs. The involvement of future teachers of various specialties in the research also increased the variability of the scenarios of application of STEM skills that were proposed by the respondents. This provided a wide range of contexts and examples reflecting how STEM education can be integrated and applied in different professional fields. Such an approach contributes to the expansion of understanding of the potential of STEM education and opens the way for the development of more effective educational programs.

4.2.4 ETHICAL CONSIDERATIONS

The study strictly adhered to ethical standards and protected the rights of the participants. Before starting, we received approval from the Research Ethics Committee of Berdyansk State Pedagogical University (Protocol No. 12.04 dated 28.08.2023).

The main principle was to ensure the confidentiality and anonymity of the respondents' answers, guaranteeing that no information, obtained from the questionnaire, would be used or disclosed in a way that would affect them personally or professionally. Before the questionnaire procedure, all respondents were given information about the purpose and nature of the study, as well as guarantees regarding the anonymity of their answers. Participation in the study was voluntary and each respondent had the option to withdraw at any time without any consequences.

4.2.5 DATA ANALYSIS AND REPORTING

In the context of our study, the analysis of the data, collected using Google Forms, was focused on the qualitative processing of the responses received. Since statistical data and correlations did not form the basis of our analysis, we focused on studying and interpreting the content of respondents' answers. This allowed us to better understand the perception and evaluation of the importance of STEM skills among teachers and future teachers of various specialties, as well as to identify key topics and directions for the further development of STEM education.

The procedure of processing the results included a thematic analysis of the answers, which allowed us to identify the main mentions of the importance of certain STEM skills and their role in the professional activity of future teachers of various specialties in the context of achieving the SDGs. In this way, it became possible to identify general trends in the perception and expectations of STEM education, as well as to collect proposals for its improvement.

The results of our research were summarized and systematized. Particular attention was paid to the identification of ideas and suggestions from respondents that can be used to develop more effective and adaptive educational programs that would meet the needs of students of various specialties and the requirements of the modern labor market. Based on them, a number of strategic

recommendations, aimed at increasing the effectiveness of the integration of STEM education into the educational process in order to achieve the Sustainable Development Goals, were proposed.

4.3 KEY STEM SKILLS IN ACHIEVING THE SDGS

4.3.1 ANALYSIS OF STEM SKILLS: VIEWS OF TEACHERS AND STUDENTS OF VARIOUS SPECIALTIES

A survey, conducted among teachers and students of various specialties of the Ukrainian pedagogical university regarding the perception of the importance of key STEM skills and a comparison of the results of the answers of two groups of respondents allowed us to draw conclusions (**Table 4.1**).

As we can see, both groups highly value technological literacy and skills, critical thinking, creativity and the ability to generate new ideas and knowledge. The respondents identify these STEM skills as key for the successful professional activity of future teachers and for the implementation of STEM education, which contributes to sustainable development. The joint recognition of their importance reflects the consensus among students and teachers that the education system should pay special attention to their development in order to promote the quality professional training of new generations of specialists ready to solve global challenges.

However, there are significant differences in the determination of priorities regarding the development of the ability for pedagogical innovations (37.3 % – students, 50.0 % – teachers, respectively) and the formation of skills for implementing interdisciplinary integration (36.1 % – students, 52.2 % – teachers). This reflects differences in the perception of needs between the two groups, where the teachers may focus on the need to review and improve approaches to learning and teaching and an interdisciplinary approach in STEM education, while for the students this may not be so obvious. Along with this, team work, flexibility as an individual's ability to adapt to changes in the educational environment, use the latest knowledge and technologies in non-standard situations, and the ability to solve problems are valued almost equally by both groups of respondents.

It is interesting that the students rate communication skills higher (42.3 %) than the teachers (28.6 %). This may reflect their awareness of the importance of global cooperation and communication. Conversely, the teachers prefer the development of problem thinking (43.4 %) and the ability to organize project-based learning (34.6 %), while the students see the need for in-depth knowledge of physics, mathematics, technology (30.1 %) and the skills of objective assessment of students' educational achievements (29.5 %). On the one hand, this indicates their recognition of the need for a strong theoretical base for a successful career, and on the other, it once again confirms that there is a certain inaccuracy in students' understanding of the main ideas and approaches of STEM education, which is not characterized by traditional assessment approaches.

There is also a difference in the views of the teachers and the students on the relevance of developing the ability to organize project-based learning, where the students give it less preference (29.1 %) as opposed to the teachers (34.6 %). This may reflect the difference in expectations and experience between them. Teachers, having more professional experience and knowledge in this field, can evaluate the effectiveness of the method of educational projects for the development of key STEM skills that a future teacher must master in order to successfully implement STEM education in professional activities. On the other hand, students may not fully appreciate the benefits of this approach due to limited experience or may prefer more traditional learning methods, with which they are familiar.

Table 4.1 Comparative analysis of key STEM skills that a future teacher should master in order to successfully implement STEM education in professional activities: views of students and teachers of various specialties

Skills	Students	Teachers
	In your opinion, what key STEM skills should a future teacher master in order to successfully implement STEM education in professional activities? (%)	
Technological skills and literacy	51.4	46.2
Critical thinking	51.2	52.2
Creativity	45.8	39.6
Ability to generate new ideas and knowledge	45.3	44
Communication skills	42.3	28.6
Ability to pedagogical innovations	37.3	50.0
Skills of implementing interdisciplinary integration	36.1	52.2
Flexibility	30.6	29.1
Deep knowledge of physics, mathematics, technologies	30.1	24.7
Skills of objective assessment of students' educational achievements	29.5	16.5
Teamwork	29.4	33.0
Ability to solve problems	29.2	31.9
Ability to organize project learning	29.1	34.6
Problematic thinking	20.8	43.4
Organizational skills	19.6	17.6
Charisma	11	11.0

The obtained results indicate a general awareness among the students and the teachers of various specialties of the importance of key STEM skills for future professional activity, as well as the need to update educational programs in accordance with modern requirements. Differences in prioritization among them highlight the need for further dialogue among stakeholders to reach consensus on understanding and implementation of STEM education. This will lay a solid foundation for training new generations to solve global problems, social and economic challenges in the direction of sustainable development.

4.3.2 SYNERGY OF STEM EDUCATION AND THE SUSTAINABLE DEVELOPMENT GOALS

4.3.2.1 THE ROLE OF KEY STEM SKILLS IN ACHIEVING THE SDGS

The data we received in the previous part of the questionnaire are not random or unexpected. In fact, they emphasize a deep understanding of the fact that STEM skills are not just learning outcomes that future teachers of various specialties must demonstrate after completing an educational program or individual educational components (learning disciplines, coursework and qualification work, practice), but critically important indicators of their ability to intellectual, personal, social, in particular, sustainable development of the world.

Deep interdependence can be seen at the intersection of STEM education and the SDGs [6, 9]. On the one hand, global goals require new solutions from science and technology; on the other hand, STEM education provides the necessary tools and contributes to the formation of the necessary skills for their development and implementation [10, 11, 13, 14]. We attempted to determine how individual STEM skills, acquired by future teachers of various specialties, contribute to the achievement of the SDGs. For this, an integrated matrix was created (**Fig. 4.1**), which illustrates the specified relationship.

The matrix was developed on the basis of data, obtained through student surveys. The selection of students as the main respondents at this stage of our research was determined by several key factors. First, students, as direct participants in the educational process, have a unique perspective and are directly interested in acquiring knowledge and skills that will be important in their future professional activities and life. They are able to assess the practical value of the learning material, particularly in the context of achieving the SDGs. Secondly, they are representatives of a new generation of specialists who have the potential to change approaches to solving global challenges, so understanding their perception and expectations of STEM education is critical for adapting and updating educational programs and its components. Thirdly, the involvement of students in the questionnaire process contributes to the formation of a responsible attitude towards their own learning and an understanding of the importance of their contribution to the sustainable development of society. This not only motivates students to take a more active approach to their own education, but also ensures

their involvement in the development of solutions to real problems that are in line with the SDGs. And finally, student questionnaires allow to assess the effectiveness and dynamics of the educational process in real time, to adapt it to modern challenges and the expectations of the student audience.

Thus, the focus on students in this study does not preclude the importance of teacher input, but it does provide important insight into the potential and direction of STEM education towards achieving the SDGs, with an emphasis on the direct experiences and expectations of those who will be the agents of this change in the future.

Fig. 4.1 Relationship between key STEM skills and the SDGs

The student survey process required the students to select five key STEM skills from the proposed list that, in their opinion, would most contribute to the achievement of each of the SDGs. Our setting of such a limit encouraged the respondents to make a more careful and critical selection, focusing their attention on the most essential and influential skills. This allowed us to gain a more accurate picture of their importance to the achievement of each of the SDGs, thereby improving the quality of the analysis we carried out in the study.

Further, the collected answers were summarized and analyzed in order to create an integrated matrix that reflects not only the theoretical, but also the practical importance of STEM education in the context of sustainable development (**Fig. 4.1**).

The research results, obtained by us, can serve as an important tool for the further development of educational programs and their components. It allows teachers to more purposefully integrate STEM skills in the context of sustainable development, ensuring the training of future professionals capable of effectively responding to the global challenges of today.

4.3.2.2 PRACTICAL APPLICATIONS OF STEM SKILLS TO ACHIEVE THE SDGS: REFLECTING THE STUDENTS' VISION

In order to deepen the understanding of how students see the application of STEM skills in real conditions to achieve the SDGs, we invited them to think about specific examples or scenarios where the use of their formed STEM skills can make a significant contribution to the achievement of the selected SDGs. This approach made it possible not only to reveal the diversity of promising ideas among students of various specialties, but also to illustrate the practical potential of STEM education in the context of sustainable development.

This task was a leading element of our survey, which allowed the students not only to select key STEM skills from a list provided, but also to reflect on their practical application in the context of SDG challenges. The received answers and their detailed analysis showed that students are aware of the essence of sustainable development and its importance. They are motivated and show the ability for creative and innovative thinking in finding solutions to solve global problems. Below we summarize the results of hypothetical scenarios, proposed by the future teachers of various specialties.

Considering the presented matrix (**Fig. 4.1**), the students emphasized the importance of technological skills and literacy as key in solving problems related to overcoming hunger, development of agriculture (SDG 2), provision of affordable and clean energy (SDG 7), water and adequate sanitation (SDG 6), promoting decent work for all and economic growth (SDG 8), developing industry, innovation and infrastructure (SDG 9).

In particular, they pointed out that these STEM skills, formed in future teachers of various specialties, will allow at a high level to use computer programs for modeling farms and the impact of different irrigation methods on the efficiency of crop cultivation, which is important for achieving SDG 2.

For SDG 6, related to access to clean water and sanitation, the students proposed the development and implementation of educational subjects that contribute to the acquisition of knowledge about effective water conservation methods and water purification technologies. Regarding SDG 8, which is about promoting decent work and economic growth, the importance of building entrepreneurial skills and digital literacy among young people is highlighted to prepare them for professional activities in high-tech industries in today's digital world.

Among other things, the students identified critical thinking and creative qualities as universal (**Fig. 4.1**). They noted that teachers who apply critical thinking will be able to inspire their students to understand the roots of poverty and develop innovative solutions to overcome it. Creativity will help to consider alternative ways of earning and social entrepreneurship that can lift people out of poverty (SDG 1).

Meanwhile, critical thinking, according to some respondents, will allow teachers to conduct discussions and research on the topic of efficient use of resources and waste production, while creativity can inspire students to develop innovative ways to recycle and reduce waste (SDG 12). Among other things, teachers can encourage students to analyze the impact of human activity on marine ecosystems, promote the development of educational projects that involve students in the protection of seas and oceans, for example, through public initiatives to clean water bodies. This will be the foundation for achieving SDG 14.

According to the students, the developed capacity for pedagogical innovation and the generation of new ideas are important for achieving the SDGs. Especially in the context of ensuring inclusive and equitable quality education, through the creation of a safer and more accessible educational environment that takes into account the individual needs of each student (SDG 4 and 5):

"I believe that our role in providing quality education for all cannot be underestimated. Creating a safe, accessible and inclusive educational environment that takes into account the unique needs of each student is key to achieving Sustainable Development Goals 4 and 5. It's not just about access to education, it's about creating conditions where everyone can be on an equal footing" (student of the 4th year of the first (bachelor) level of higher education, specialty "Special Education").

According to the students, teachers who can generate new ideas are able to motivate students to actively participate in environmental protection, developing in them not only knowledge, but also responsibility and care for nature. In particular, they will contribute to the development of environmental awareness through involvement in real nature conservation projects, such as tree planting programs or conservation of local biotopes. Over time, this will play an important role in achieving SDG 15:

"I think if children are more involved in projects, such as planting trees or protecting our local biotopes, it will help them better understand why taking care of nature is so important. Actions like these can really help us all become more eco-conscious. And in the end, this will help to achieve SDG 15" (student of the 2nd year of the first (bachelor) level of higher education, specialty "Biology and human health").

In particular, referring to the students' answers, we note that teachers who are capable of pedagogical innovation and generating new ideas can encourage students to study alternative energy sources, a deeper understanding of global energy challenges and how different energy sources

affect the environment and the economy. They can hold discussions and debates on the topic of energy policy, stimulating students to reflect and put forward their own proposals (SDG 7).

Given the results presented in the matrix (**Fig. 4.1**), the skills of implementing interdisciplinary integration and flexibility in the future professional activities of teachers of various specialties are also vital for the formation of students' understanding of the complex problems facing the world. Teachers can combine knowledge from different subjects (physics, chemistry and engineering and others) in order to form in students an idea of how energy is produced, distributed and consumed (SDG 7):

"If in geography lessons we talk with children about how windmills and solar panels can change people's lives and nature for the better, it will be cool. And in physics, we can see how they actually work, make a small solar station or a windmill, and in the lessons "I explore the world" we can talk with children about why not all countries use "green" energy and how it threatens the world in the future and what to do with it" (student of the first year of the second (master's) level of higher education, specialty "Physics and Astronomy").

In this way, according to the students, they can increase their awareness of global climate change, its causes and consequences, as well as strategies and methods for their mitigation (SDG 13), preservation of marine resources (SDG 14). At the same time, teachers who possess flexibility can adapt the content of their curricula and lessons to the challenges of today, such as natural disasters, global warming or the environmental consequences of military conflict.

Among other things, students highly appreciated the importance of communication and organizational skills, the ability of teachers of different specialties to work in a team (**Table 4.1**) and gave examples of their application to achieve the SDGs (**Fig. 4.1**).

Teachers who have developed communication skills, in their opinion, can communicate effectively with students from different social groups, taking into account their individual needs and cultural contexts. This allows them to be more tolerant, sensitive to issues of inequality and develop curricula that raise students' awareness of global inequalities and ways to overcome them (SDG 10). Teamwork and organizational skills help them build an inclusive educational environment that cultivates mutual respect and understanding, which are important for maintaining peace and justice (SDG 16):

"When we all know how to work together, learning becomes much cooler. We learn to listen to each other and respect different opinions. It's like creating a place where everyone is comfortable and everyone understands each other, and this is very important, so that there is less inequality and more justice in the world" (student of the 3rd year of the first (bachelor's) level of higher education, specialty "Elementary Education").

According to the respondents, communication skills and effective teamwork are the basis for creating and maintaining partnerships with state authorities, educational institutions, scientific institutions, representatives of business and industry, and the public:

"Well, in my opinion, if you can get along well with people and work in a team, it opens a lot of doors. You can cooperate with the government, schools, scientists, business – with everyone who can help us in our studies or do something useful for the community. It's like when you know how to play team games, you know how to achieve goals together, and it helps us all work better" (student of the second year of the first (bachelor's) level of higher education, specialty "Management").

This collaboration, as indicated by the students, can be important for providing a favorable environment that will ensure the realization of STEM education, guaranteeing a systematic and coordinated approach to its implementation at the level of educational institutions, in particular, the exchange of resources, ideas and best practices, aimed at increasing sustainability and efficiency of educational initiatives (SDG 17). All these together form a strong foundation for the effective implementation of sustainable development initiatives, which will ultimately contribute to the achievement of SDG 11.

4.3.2.3 APPLYING STEM SKILLS TO ACHIEVE THE SDGS IN WAR AND POST-WAR RECONSTRUCTION

Our analysis becomes especially relevant in the context of the ongoing war in Ukraine and its post-war reconstruction. War not only leads to environmental problems due to emissions and pollution, but also poses a constant threat to national security and territorial integrity, causes the destruction of civilian infrastructure [28, 29], human losses and forced displacement of citizens [30]. This poses difficult tasks for the higher education system to adapt the content of educational programs to new realities, to form the necessary skills in students and future generations to overcome the challenges of war, emphasizing the importance of sustainable development as a basis for the reconstruction and future prosperity of the country. This involves integrating the principles of environmental sustainability, economic responsibility, and social justice into educational programs, as well as promoting youth's understanding of the relationship between peace, security, and sustainable development to ensure effective participation in the country's recovery process. Therefore, our attempt to explain the relationship between STEM skills and the SDGs acquires not only theoretical, but also practical significance, pointing to ways, in which education can contribute to solving specific problems, caused by the war.

In the context of these challenges, we decided to directly address the students of various specialties with a key question that will help to better understand and evaluate the possibilities of applying STEM education in solving the urgent problems that Ukraine faces during the war and in the process of post-war reconstruction. We asked the students: "Describe how the application of the STEM skills you indicated can help Ukraine achieve the Sustainable Development Goals during the war and in the process of post-war reconstruction?".

According to the students, teachers with technological skills and interdisciplinary knowledge can initiate and manage projects for students that contribute to the development of innovative solutions for water purification and recirculation. This not only contributes to the achievement of Sustainable Development Goal 6, but also forms the basis for the recovery and development of the country in the long term.

Meanwhile, the problem of developing and implementing the latest defense technologies and cyber defense systems to protect state structures is becoming very urgent. Future teachers who are knowledgeable about technology and cyber security can help raise students' awareness of cyber hygiene and the basics of cyber security (SDG 9):

"As a student majoring in Vocational Education (Digital Technologies), I believe it is super important to learn new technologies to protect our government systems. Simply put, we have to be one step ahead of hackers, so that our country is safe" (4th year student of the first (bachelor's) level of higher education, specialty "Professional Education (Digital Technologies)").

Despite everything, it is important to ensure the continuity of the educational process in the conditions of the military conflict. According to the respondents, teachers who are capable of pedagogical innovations can use digital tools to provide access to quality education to all students, including those who are in conflict zones or have been forcibly relocated to safer regions of Ukraine or abroad. They can also contribute to the creation of an inclusive educational environment in educational institutions, ensure the flexibility of educational programs, diversify or change methodologies, methods and approaches to learning taking into account the needs, interests and characteristics of students (SDG 4).

After hostilities end, the main goal becomes the restoration of peace, justice and social institutions (SDG 16). In their answers, the students indicate that teachers can use their organizational and communication skills to initiate projects, aimed at developing inclusive educational programs, social cohesion, and supporting the mental health of the population, especially those with disabilities, victims of hostilities, and those belonging to vulnerable categories of the population. Thus, the STEM skills of future teachers of various specialties will play a key role in supporting Sustainable Development Goal 16, allowing not only to develop and implement innovative technological solutions to support peace and justice, but also to prepare the younger generation to solve the challenges of the modern world and rebuild societies after the conflict.

4.4 STRATEGIC RECOMMENDATIONS FOR THE INTEGRATION OF STEM EDUCATION AND THE SDGS

Given the importance of the impact of STEM skills in achieving the SDGs, the analysis, carried out within the framework of our research, emphasizes the urgent need for a comprehensive transformation of educational programs in order to provide students with a set of specific skills that will allow them to respond effectively to the changes and challenges of a changing world. The implementation of the above requires coordination of efforts and cooperation between various

interested parties: from state authorities to representatives of educational institutions, scientific institutions, business, industry, and the public. It is necessary to emphasize the importance of international cooperation in the field of STEM education and the SDGs for the exchange of experience, since such mutual exchange opens access to methods and innovative solutions that have long been successfully implemented in other countries [20–22].

However, in our opinion, in order to ensure the effective implementation of STEM education at the level of higher education institutions in order to achieve the SDGs, it is necessary to focus not only on the content of educational programs and its components (curriculum disciplines, coursework and qualification work, practice), but also on the diversification of methods, techniques and approaches to student education taking into account the needs of students and the labor market. In the future, this will guarantee that they will obtain those learning results that will determine their ability to successfully carry out professional activities within the chosen specialty, provide them with real experience and prepare them for active participation in solving global problems.

Table 4.2 presents strategic recommendations that should be considered when implementing the steps suggested above. They were developed on the basis of an in-depth analysis of responses to the assessment of the importance of STEM skills among students and teachers of various specialties and understanding how exactly students see the application of STEM skills to achieve the SDGs in real-world settings through the analysis of concrete examples and scenarios.

A key aspect of the strategic recommendations is their focus on defining the main forms and means of their implementation, including the development of interdisciplinary courses, encouraging the development and implementation of projects, aimed at solving specific tasks in the field of SDGs, the use of modern technologies and platforms for learning, as well as active learning methods. In addition, methods of involving students in various activities and potential partners, whose experience can be used to improve the STEM skills of future teachers of various specialties, are specified.

The expected results from the implementation of the strategic recommendations, indicated in **Table 4.2**, cover a wide range of positive changes both for students of various specialties and for the higher education system as a whole.

Students will acquire critical competencies including critical thinking, creativity, teamwork skills, and cognitive flexibility that are essential to successfully address today's sustainable development challenges. In particular, they will receive more thorough knowledge and practical skills in the application of digital technologies and data analysis methods.

One of the key directions of increasing the effectiveness of pedagogical education is to overcome the existing gap between the theoretical foundations of pedagogy and the practical application of STEM skills. In the context of this task, the integration of interdisciplinary projects into the educational process is of particular importance, which is demonstrated in **Table 4.2** on the example of the development of sustainable urban development projects. The implementation of such projects contributes not only to students' in-depth understanding of the multifaceted challenges of sustainable development, but also gives them the opportunity to apply theoretical knowledge in real practical contexts, contributing to their professional growth.

Involving students of various specialties to participate in joint projects with local communities, representatives of the industrial sector and international organizations creates conditions for the direct application of skills, acquired within the framework of STEM education, for the implementation of local initiatives that contribute to sustainable development. The implementation of projects on a wide range of topics, including but not limited to the development of environmentally safe energy solutions, improvement of agricultural technologies, etc., aimed at meeting the specific needs of society, demonstrates to students the role and importance of STEM skills in solving practical tasks of today. This approach not only contributes to students' deep understanding of the practical importance of their knowledge and skills, but also educates future teachers of various specialties to a high degree of social responsibility, awareness and readiness to actively influence the processes of sustainable development. As a result, students who go through such an educational experience turn into conscious and proactive citizens, highly motivated to build a just world.

For the system of higher education, the introduction of innovative methods and approaches to education, focused on solving current problems, will increase the quality of education and make educational programs more relevant in accordance with the needs of the modern labor market. The involvement of teachers in continuous learning and development of professional competences will ensure a high level of teaching, conducive to an innovative and effective educational process. It is also important to establish a partnership with representatives of industry, business, and the public, scientific institutes, which opens up new opportunities for practical cooperation, joint research and combining theory with practice.

The implementation of the strategic recommendations on the integration of STEM education and the SDGs at the level of higher education institutions, presented by us in **Table 4.2**, is accompanied by numerous challenges and risks. These difficulties arise from the complexity of the task itself, which involves a deep transformation of traditional educational approaches, the need to update the content of educational programs, involve teachers in continuous professional development, as well as the integration of advanced technologies and teaching methods. However, it is important to understand that opportunities are along with the challenges and risks. They should be perceived as a powerful stimulus for change and innovation in higher education, pointing the way to creating a more flexible, adaptive and responsible educational system.

Taking into account the presented strategic recommendations, higher education institutions have the opportunity to significantly improve the integration of the SDGs into the process of professional training of future teachers of various specialties. Their implementation will allow not only to update educational programs and the practical component of the organization of the educational process, making them relevant to modern challenges and needs of society, but also to significantly expand the use of innovative approaches and technologies, which are key in STEM education. This will contribute to students' formation of the necessary STEM skills and professional competences, in particular, for active participation in solving complex problems facing the modern world in the context of SDGs. Therefore, these strategic recommendations will become a reliable basis for improving the quality of the educational process and training qualified specialists capable of making a significant contribution to the sustainable development and post-war reconstruction period of Ukraine.

Table 4.2 Strategic recommendations for the integration of STEM education and the SDGs at the level of HEIs

Recommendation	Forms and means of implementation	Potential partners	Expected result	Challenges and risks
1	2	3	4	5
Development of interdisciplinary courses with a focus on the SDGs	The academic discipline "Innovations for Sustainable Development" is focused on the development of solutions to achieve the Sustainable Development Goals at the local level by students working in multidisciplinary teams. Organization of guest lectures involving specialists from the field of education, representatives of industry, business, and the public for exchange of experience, discussions, practical ideas and development of cooperation	Institutions of higher education with adaptive programs, focused on sustainable development. Non-governmental organizations and foundations, representatives of business and industry. Research institutes	Development of critical thinking and creativity in students, as well as their mastery of the skills of solving actual problems through work on local practical cases, such as sorting waste in communities and combating gender stereotypes in the workplace, etc.	Ensuring a high level of interest and motivation among students to study a new academic discipline and participate in interdisciplinary projects. The need to update and demonstrate the practical significance of the course for training future teachers of various specialties. The need for constant updating of the content of the academic discipline in order to adequately reflect modern challenges and trends of sustainable development
Application of the project approach	Organization of semester projects that ensure active participation of students in real research and practical initiatives, focused on sustainable development. These projects should be aimed at solving specific problems, identified in cooperation with local communities, public organizations, industrial partners and other interested parties	Local public organizations. Local government and state institutions. Non-governmental organizations and foundations, business and industry. Research institutes	Increasing the level of organizational and communication skills of students, developing critical thinking skills, teamwork, creative qualities and cognitive flexibility. Formation of a responsible attitude of students to the educational process and the performance of tasks. Mastering project management skills	Insufficient experience and training of teachers to develop and manage students' projects. Lack of unified evaluation criteria for multidisciplinary and innovative projects. Limited access to advanced technologies and resources in some HEIs. Constant need to ensure effective interaction between project participants and partners
Ensuring the development of students' technological literacy	Implementation of an integrated course that focuses on learning data analysis methods, ethical aspects of using digital technologies, and their application to achieve the Sustainable Development Goals. Practical application of digital technologies within various educational disciplines.	rganizations that offer trainings and courses to improve technological literacy. Technology companies. Non-governmental organizations and foundations. Research institutes	Increasing the level of students' technological literacy. Increasing their awareness of digital security. Increasing the level of development of psychomotor skills related to the correct and safe use of scientific and technical equipment, devices and	Lack of hardware, software or funding. Resistance to the introduction of innovations on the part of teachers and administration of the higher education institution. The need to train teachers, increase their direct technological literacy and skills. Keeping the learning material up-to-date requires constant updating of the course

Continuation of Table 4.2

1	2	3	4	5
	Development of interdisciplinary projects that encourage students to apply acquired technological skills in real situations. Inclusion of programming and cyber security modules to expand students' technological competencies and increase their awareness of digital security		substances, specific for a certain industry, predictive and corresponding to the dynamics of the labor market	to keep it relevant and up-to-date
Stimulating the development of students' critical and problem-oriented thinking	Application of problem-oriented tasks that require in-depth analysis and problem solving in unfamiliar contexts for the development of students' analytical abilities. Organizing debates and discussions on SDG topics as a means to stimulate critical thinking, discussion of diverse views and opinions. Use or implementation of interactive learning methods, aimed at studying the main ideas of the concept of sustainable development. Development of skills of critical analysis of scientific sources, by assessing the reliability and significance of scientific data and information	Practitioners who can be involved in conducting guest lectures, workshops or acting as experts or moderators of student debates on SDG issues. Research centers and institutes. Non-governmental organizations working on the Sustainable Development Goals. Technology companies	Development of the ability for deep analysis and critical thinking through work with problem-oriented tasks in various contexts. Development of argumentation skills, the ability to discuss various points of view and form one's own opinion. Increasing the level of students' motivation for more active participation in the educational process, contributing to a deeper understanding of the concept of sustainable development. Improving the skill of critical analysis of scientific sources	The need to improve the qualifications of teachers to facilitate problem-oriented learning and conduct effective debates. Lack of access to the necessary interactive resources or limited time for classes. Low motivation of students to participate in debates and work on problem-oriented tasks. Lack of clear, objective and fair criteria for evaluating students' progress in critical thinking and problem-oriented learning. The challenges are related to the integration of new methods into the existing educational components, provided that academic standards are preserved. Resistance on the part of students to active learning methods or teachers regarding their implementation. Ensuring inclusiveness and accessibility of debates and discussions
Organization of student teamwork	Practice of public speaking in front of an unfamiliar audience in order to present the results of research projects, aimed at solving current problems in the context of SDGs. Integration into the educational process of tasks that require joint work of	Local enterprises and startups. Non-commercial organizations. Professional associations and unions. Career and leadership development centers	Development of argumentation skills, the ability to discuss various points of view and formulate one's own opinion. Increasing the level of organizational and communication skills of students, teamwork skills,	The need to provide equal opportunities for all students to participate in teamwork, regardless of their experience and skills. The risk of conflicts or uneven distribution of roles/work in teams, which can negatively affect work performance. Insufficient number of mentors with the

Continuation of Table 4.2

1	2	3	4	5
	students in teams, to solve educational cases or develop projects. Organization of trainings and workshops on team interaction. Engagement of mentors from the academic community to provide feedback and mentoring to student teams during project work. Organization of interactive sessions with case methods, where student teams analyze and discuss real cases from practice, aimed at achieving the SDGs		development of creative qualities and cognitive flexibility. Gaining experience in presenting research projects to a wide audience. Increasing the level of activity and initiative of students in the educational process	necessary knowledge and experience for effective mentoring. Limited resources (both financial and technical). Low level of motivation of participants to join team activities
Involvement of teachers to continuous professional development on integration of STEM education and the SDGs	Organization of master classes, seminars and workshops, aimed at improving the qualifications of teachers in the field of advanced methods of integration of STEM education and the sustainable development goals. Participation in academic and research projects, as well as scientific conferences, which will contribute to the exchange of professional experience. Implementation of mentoring programs for studying and implementing the STEM approach in the educational process. Establishing cooperation with enterprises and organizations that actively use STEM in the context of sustainable development, for example in the form of internships. Development and dissemination of educational materials (e.g. e-books, interactive guides) that detail best practices and teaching methods	Institutions of higher education and research institutes. Enterprises and startups in the field of technology. International organizations and foundations. Non-commercial organizations. Representatives of platforms of open mass online courses (for example, Coursera, Prometheus, EdEra, etc.)	Improving the qualifications of teachers – acquiring knowledge and skills in the field of advanced methods of integration of STEM education and the sustainable development goals. Development of teachers' ability to adapt and quickly respond to changes. Stimulation of teachers' creative thinking. Ensuring the availability of advanced knowledge for a wide range of teachers	Part of teaching staff may show resistance to innovations, considering the existing methods to be effective enough. The rapid development of technologies and methods requires constant updating of materials, which can be a time-consuming process. The need to involve experienced mentors who can effectively transfer knowledge and experience to participants. Low level of motivation among teaching staff due to their high workload. Compliance of the content of professional development programs with current requirements in the fields of STEM and the SDGs. Lack of sufficient financial resources for effective implementation of professional development programs for teachers. Expanding access to professional development programs through the introduction of distance learning forms

4.5 CONCLUSIONS

In the process of the research, an in-depth analysis of the place and role of STEM education in achieving the SDGs and its significance for the national revival of Ukraine was carried out. It is emphasized that STEM education not only contributes to the formation of fundamental knowledge and skills in the field of science, technology, engineering and mathematics, but also becomes a key catalyst of socio-economic changes, playing a decisive role in the modernization of society and strengthening its sustainability.

Attention was drawn to the fact that the introduction of STEM education contributes to the improvement of the quality of education in general, ensuring the formation of students' technological skills and literacy, critical thinking, creativity, the ability to generate new ideas and innovative problem solving. These skills are indispensable for the formation of a new generation of specialists – teachers of various specialties who are able to effectively respond to modern global challenges and contribute to the sustainable development of society. Special attention was paid to the potential of STEM education in increasing the national competitiveness of Ukraine and its potential for the post-war recovery, ensuring future prosperity and sustainability.

One of the key findings of our study was the identification of significant differences in perceptions of important STEM skills for achieving the SDGs between student teachers of various specialties and teachers. On the one hand, students highly value technological skills, critical thinking and creativity, seeing them as fundamental for their future professional activities. On the other hand, teachers emphasize the importance of pedagogical innovations, interdisciplinary integration and the development of problem thinking. These differences in perception between students and teachers require higher education institutions to carefully analyze and update their educational programs in such a way that they meet the needs of students of various specialties and the modern labor market, as well as ensure effective assimilation of knowledge and skills necessary for effective solutions to modern challenges. This places a great responsibility on them and requires the involvement of a wide range of interested parties, including state authorities, representatives of educational institutions, scientific institutions, business and industry, and the public. Each of these participants plays a unique role in shaping and maintaining an effective STEM education system, aimed at achieving the SDGs.

State authorities can create and support the legislative and financial framework for the integration of STEM education in all HEIs. This may include the involvement of international partners in cooperation, increased funding for the implementation of the STEM approach, the creation of funds and grant programs for educational institutions, teaching staff and students; introduction of tax benefits for companies investing in the development of STEM education. In particular, state authorities can promote the development of youth STEM skills necessary to achieve the SDGs through the implementation of incentive measures for HEIs that actively integrate sustainability principles into their educational programs. This may include establishing accreditation standards that take into account and reward educational initiatives, aligned with the Sustainable Development Goals,

and providing financial support or other types of incentives for those institutions that demonstrate a high level of implementation of sustainability principles in the educational process.

Institutions of higher education, in turn, are responsible for developing and updating educational programs and their components, so that they meet the modern requirements of the labor market and emphasize the importance of sustainable development. Meanwhile, their cooperation with scientific institutions to conduct joint research that will contribute to innovations in the field of STEM education will be fruitful, in particular, they will play a key role in forming a practical base, giving students the opportunity to engage in real research projects. Business and industry provide the best platform for internships and mentorship for students, helping them apply skills in real-world settings and understand market needs. Cooperation between higher education institutions and high-tech companies can contribute to equipping and creating specialized laboratories and research centers, where students have the opportunity to work on innovative projects in the field of renewable energy, ecology and other key areas. The public and non-governmental organizations can promote the idea of the importance of STEM education through information campaigns, raising public awareness of the SDGs and the need to integrate them into the educational process of higher education. Collectively, the efforts of all stakeholders should be aimed at creating an integrated, multifaceted STEM education system that will ensure the formation of the necessary skills among young people and contribute to the achievement of the SDGs.

Based on the analysis, strategic recommendations for higher education institutions were formulated, which are aimed at ensuring the formation of key STEM skills important for achieving the SDGs in future teachers of various specialties: develop interdisciplinary courses with an emphasis on SDG challenges; promote the application of a project approach, which will involve the cooperation of students with local public organizations or other stakeholders working on initiatives in the context of sustainable development; ensure the development of students' technological literacy and skills; stimulate them to develop critical and problem-oriented thinking by including in the curriculum special tasks that require analysis and finding solutions in an unfamiliar situation, conducting debates and discussions, role-playing games on SDG issues to encourage the analysis of different views; promote the organization of student teamwork (performance of team educational tasks, public presentation of a joint project, etc.) and the involvement of teachers in continuous professional development on issues of integration of STEM education and the SDGs.

The implementation of the proposed strategic recommendations will undoubtedly require significant efforts from all stakeholders. However, the reward is worth the effort. The society will receive teachers of various specialties who will be able to solve the urgent challenges of modern times with the help of their knowledge, creativity and commitment to the ideas of sustainable development. They will teach new generations, laying the foundation for a future where innovation and responsible treatment of resources will be the main guidelines. Thus, in the long term, the majority of citizens of our country will be aware of the problems of sustainable development and able to apply an interdisciplinary approach to solve them at different levels. Through targeted action and

collaboration with stakeholders, higher education can ensure the training of young people who will be at the forefront of defending peace, justice and sustainable development.

Summarizing, it should be said that this study makes a significant contribution to the discourse on the need for further integration of STEM education and the SDGs, especially in the context of the current situation in Ukraine and the future period of its recovery. It is becoming clear that investing in STEM education, focused on practical problem solving, will play a crucial role in shaping the country's sustainable future. This will not only contribute to the achievement of specific SDGs, but will also ensure the long-term development of Ukraine as a strong, independent and innovative state.

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