Прототип цифровой экосистемы для исследовательской деятельности магистрантов

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АННОТАЦИЯ

Введение. В условиях цифровизации достаточно актуален вопрос внедрения в организацию исследовательской и инновационной деятельности современных информационных технологий, технологий краудсорсинга, акселерационных программ, цифровых ресурсов и систем. В контексте исследования представляется возможным выявить потенциал использования цифровых образовательных экосистем для решения проблемы взаимодействия сервисов и приложений, работающих совместно для расширения и обеспечения исследовательской деятельности магистрантов.

Цель исследования – разработка прототипа цифровой экосистемы исследовательской и инновационной деятельности магистрантов на основе микросервисной архитектуры.

Материалы и методы. Метод анализа информационных источников с применением агрегатора научных публикации (Lens.org) и анализа данных (VOSviewer). *Метод моделирования.* Использована методология функционального моделирования, предназначенная для формализации и описания процессов по стандарту IDEF0. Для обмена данными в цифровой образовательной экосистеме используется архитектурный стиль REST.

Результаты исследования. В результате создан прототип цифровой экосистемы исследовательской и инновационной деятельности магистрантов, представляющий собой единую, взаимосвязанную, процессуальную систему, объединяющую различные необходимые сервисы и приложения, она охватывает спектр педагогических функций для расширения и обеспечения исследовательской деятельности магистрантов. Уточнены организационно-педагогические условия использования цифровой экосистемы в процессе подготовки магистрантов.

Заключение. В ходе проведенного исследования обоснован педагогический потенциал цифровых образовательных экосистем на основе нового базиса и выявленных ранее эмерджентных свойств. Определена структура, технологии, содержание элементов цифровой экосистемы с использованием микросервисной архитектуры.

КЛЮЧЕВЫЕ СЛОВА

цифровая образовательная экосистема, цифровизация образования в вузе, прототип цифровой экосистемы, исследовательская деятельность магистрантов

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A prototype of a digital ecosystem for undergraduates' research activities

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ABSTRACT

Introduction. In the context of digitalization, the attention of scientists is shifting to solving issues of introducing research and innovation activities into the organization using modern information technologies, crowdsourcing technologies, acceleration programs, digital resources and systems. In the context of the study, it is possible to identify the potential of using digital educational ecosystems to solve the urgent problem of interaction between services and applications working together to expand and support the research activities of undergraduates.The purpose of the development of a prototype of a digital ecosystem of research and innovation activities of undergraduates based on microservice architecture.

Materials and methods. The method of analyzing information sources using the aggregator of scientific publications (Lens.org) and data analysis (VOSviewer).

The modeling method. The methodology of functional modeling is used, designed to formalize and describe processes according to the IDEF0 standard. The REST architectural style is used for data exchange in the digital educational ecosystem.

Results. As a result, a prototype of the digital ecosystem of research and innovation activities of undergraduates was created, which is a single, interconnected, procedural system combining various necessary services and applications, it covers a range of pedagogical functions to expand and ensure the research activities of undergraduates. The organizational and pedagogical conditions for the use of the digital ecosystem in the process of training undergraduates have been clarified.

Discussion and Conclusion. In the course of the conducted research, the pedagogical potential of digital educational ecosystems is substantiated on the basis of a new basis and previously identified emergent properties. The structure, technologies, and content of elements of the digital ecosystem using microservice architecture are determined

KEYWORDS

digital educational ecosystem, digitalization of education at the university, prototype of the digital ecosystem, research activities of undergraduates

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INTRODUCTION

According to UNESCO's medium-term strategy project for 2022-2029, addressing issues related to technological development should focus on adapting legislation and strategic frameworks to diversify the digital ecosystem and foster the creation, discovery, and dissemination of diverse content [1]. One of the strategic goals in the field of digital transformation in science and higher education in the Russian Federation is the creation and development of a unified ecosystem of services for conducting research and development to improve their quality and accessibility, as well as to reduce fixed and variable costs by creating a unified research exchange and the necessary infrastructure [2].

The ecosystem approach is widely discussed in education; despite certain results, it is still in the formative stage. Despite the variety of definitions for a digital educational ecosystem, consensus has yet to be achieved. The contradictions between the rapid development of digital ecosystems in the economy (Alibaba, Amazon, Google, Microsoft, Yandex, and others) and the need to realize their potential for pedagogical applications in graduate students' research activities require justification of the pedagogical basis on which a digital ecosystem for these purposes can be built.

On the one hand, there is positive practice in applying digital ecosystems in socio-economic life. In their competition for consumers, they improve the quality and range of services, significantly enhance life comfort, and exhibit a dynamic development characteristic necessary for their sustainable existence. According to experts, the future of the economy lies with them. On the other hand, there is a gap between pedagogy and the information technology sector. This is indirectly due to the limited publications of unique, world-class experts – ecosystem designers. Limited scientific publications on conceptual apparatus issues (essence, structure, properties, etc.) in "digital ecosystems" have led to a need for viewing video conferences and dialogues to identify aspects beneficial for the educational system.

Using the scientific publication aggregator (Lens.org) and tools for identifying matching keywords in English-language scientific texts (VOSviewer), an analysis was conducted on the use of the terms “digital ecosystem” and “digital educational ecosystem.” Maps of term interrelations and significance in application areas were created [3].

It was found that for more accurate conclusions, it is necessary to consider teachers' experiences and perspectives on the digital educational ecosystem, enriching them with new concepts from information technology. Firstly, it is essential to identify obstacles to realizing the pedagogical potential of the digital ecosystem, and secondly, to substantiate a pedagogical basis that includes the development characteristics of the digital ecosystem (considering issues in the field of information technology).

In pedagogical research related to digitalization, the following opinions are noted [4]:

- IT plays a significant role in the transition from traditional teaching methods to collaborative methods using Virtual Learning Environments (VLE), Massive Open Online Courses (MOOC), Open Educational Resources (OER), and Learning Management Systems (LMS);
- The high dynamics and wide spread of digital systems contribute to lifelong learning, individual educational paths, access to global resources, and the interaction of educational process participants;
- Digital educational ecosystems represent interconnected digital platforms, resources, and tools, aiming to support the educational process;
- A digital educational ecosystem is a complex digital system consisting of various applications, including learning management systems and social networks.

In the information technology sector, the following logic prevailed: after Arthur Tansley introduced the term “ecosystem” in the 1930s in biology to denote local communities of organisms interacting with the environment, evolving together, and adapting to changes [5], the concept of a digital business ecosystem emerged in 2002, with its application in e-commerce suggested by P. Dini and

G. Lombardo [6]. An ecosystem-oriented architecture (EOA) was created (G. Briscoe, S. Sadedin, P. De Wilde) [7]. Similar to biological ecosystems, digital ecosystems possess properties of self-organization, scalability, and resilience. EOA automates the search for new algorithms in scalable architectures by evolving software services in distributed networks, which helps overcome challenges with contemporary development methods.

Following the introduction of new methods for organizing value (O. Valdez-De-Leon), ecosystems are defined as open networks of organizations connected in a digital format and supported by modularity. Three elements are crucial for success: platform, network effects, and market expectations. Without a platform, an ecosystem cannot exist; its key properties are openness, modularity, and quality [8]. Network effects ensure a constant increase in participants and products on the platform, raising interest in it [9; 10]. Ecosystem leaders must create favorable conditions, support participants, and promote value creation for users [11]. Digital ecosystems are described by H. Boley and E. Chang as a new network architecture and collaborative environment that overcomes the limitations of client-server, peer-to-peer, network, and web services [12].

The concept of a “digital ecosystem” is regarded by authors N. Alsufyani and A. Q. Gill as a network of interconnected organizations, people, and entities collaborating for co-generating value. The authors analyze approaches to modeling digital ecosystems and select adaptive enterprise architecture as a benchmark due to its relevance to different ecosystem levels [13]. X. Xue and G. Li argue that digital ecosystems evolve as open, flexible, clustered, and demand-oriented systems. They propose a new approach to building a digital ecosystem based on swarm intelligence [14]—a paradigm for working with complex systems, representing reliable, scalable, and self-organizing behavior for working with dynamic systems [15]. Definitions of the digital ecosystem also include an integrated digital environment consisting of many interconnected services and applications that work together to provide users with a wide range of functions and services [16].

Major Russian companies such as Sberbank, Yandex, Mail.ru Group, MTS, and others are actively developing their own digital ecosystems. To ensure seamless and reliable operation, they employ modern architectural approaches. F. Rademacher highlights the growing need among IT companies for flexibility and improved delivery cycles. Microservice architecture – a new approach to software architecture design – aims to enhance scalability, maintainability, and reliability. To achieve this, it is recommended to divide the architecture into microservices, each representing an independent component responsible for specific functions and interacting with each other [17]. H. Zhang examined the gap between theoretical views and real-world practices of microservices in the industry, identifying issues such as organizational changes, decomposition, distributed monitoring, and localization [18]. A microservice architecture application is a distributed application where all its modules or elements are microservices, allowing them to run independently [19].

According to the online publication TAdviser, there are currently over 400,000 graduate students in Russia – potential users of the digital ecosystem [20]. With such a user base, a microservice architecture can significantly simplify system management, scalability, and development, while ensuring high reliability [21].

Thus, considering the views of information technology industry experts, the following definition was clarified [4]: “digital ecosystem for activating the research and innovation activities of graduate students” is a complex system of digital technologies, tools, resources, and services that are integrated and interconnected to achieve the goals of education and research. It includes engaged and interacting stakeholders – teachers, learners, administrators, researchers, and others – through technological resources and services. It possesses new emergent properties, including network effects for realizing the pedagogical potential of internet socialization; use of collaborative project intelligence in joint educational activities; leveraging the pedagogical potential of previously unknown patterns and opportunities revealed through big data analysis and machine learning algorithms; acceleration of innovative educational processes; and promotion of social norms and values, leading to new cultural trends.

The study resulted in a firm understanding that developing graduate students’ research competencies is severely hindered without engagement in digital educational ecosystems in the current development stage. The creation of a digital ecosystem based on microservice architectures enables the division of complex systems into smaller, independent components, simplifying their development, testing, and maintenance. Moreover, digital ecosystems contribute to the emergence of new cultural trends, making it essential to include the educational community in the ecosystem creation process to introduce positive social practices and ethical standards in graduate students' research activities.

The research objective is to develop a prototype of a digital ecosystem for graduate students' research and innovation activities based on microservice architecture.

MATERIALS AND METHODS

The research is based on an analysis of information sources dedicated to various aspects of the digital educational ecosystem, utilizing materials from leading scientific journals indexed in Web of Science and Scopus databases, as well as publications from open scientific libraries such as eLibrary.ru, CyberLeninka, Annual Reviews, and others. With the application of publication aggregation tools (Lens.org) and data analysis tools (VOSviewer), an analysis of key terms "digital ecosystem" and "digital educational ecosystem" was conducted. This enabled the collection of a wide range of information on different aspects of the digital educational ecosystem.

For analyzing the informational structure of the digital ecosystem prototype under development, an IDEF0 model was used, through which the process of digital ecosystem development was decomposed. The architectural style REST was used for data exchange within the digital educational ecosystem, which is based on using standard HTTP methods and principles for creating and manipulating resources.

RESEARCH RESULTS

The process of modeling the digital ecosystem for graduate students' research activities involves establishing sequentially executed stages (which must be decomposed and fully detailed), ordering them over time, creating interconnections, and consolidating them into stages of work (the execution of which is necessary and sufficient to build a system) that meets the specified requirements. The IDEF0 process modeling standard was applied as a tool for analyzing the informational structure of the prototype under development, providing a clear representation of its components and interconnections in Figure 1. For the IDEF0 model, it is essential to define the primary functions and processes to be included in the model, as well as their interrelationships.

The integration of digital ecosystem components enables seamless, uninterrupted, and timely functionality for more efficient problem-solving; each component operates collectively, creating a unified mechanism that maximizes the speed and transparency of processes across various areas of activity. Additionally, microservice architecture was used in development, which entails dividing the system into small, independent services, each performing a specific task. This approach ensures high flexibility, scalability, and fault tolerance [22]. Microservices interact using various types of requests and protocols. The interaction method includes HTTP/HTTPS requests with REST API and message exchange through message queue systems or message brokers. Data exchange utilizes the REST architectural style, which relies on standard HTTP methods and principles to create and manage resources [23]. REST is an interaction style that uses standard HTTP methods (GET, POST, PUT, DELETE) to perform operations.

The microservice architecture scheme of the designed digital educational ecosystem is shown in Figure 2. The API gateway processes requests and forwards them to the microservices. Each microservice's API defines request handling and data provision. Microservice architectures overcome the limitations of monolithic architectures [24]. A monolithic architecture enhances performance, scalability, flexibility, and reliability [25]. A container-based microservice architecture for cloud applications is used by major European e-commerce platforms [26].

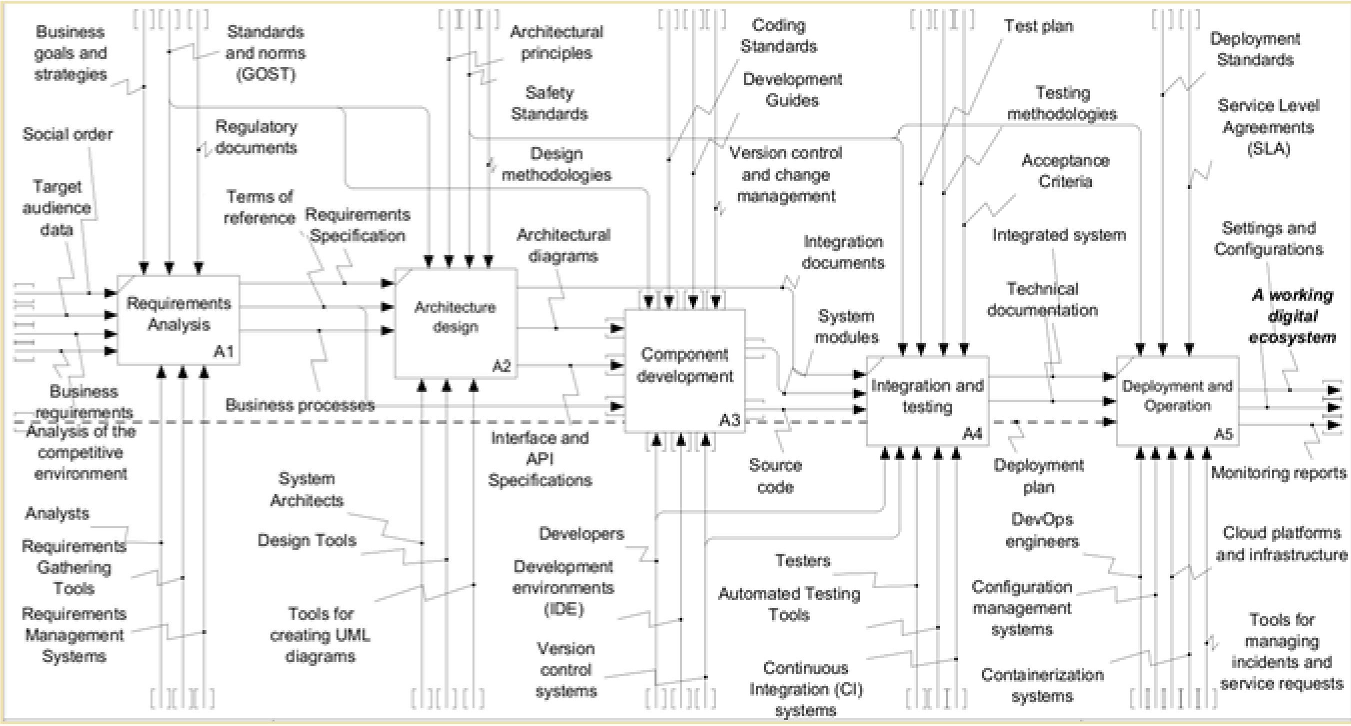

Figure 1 IDEF0 Context Diagram: Development of the Digital Ecosystem

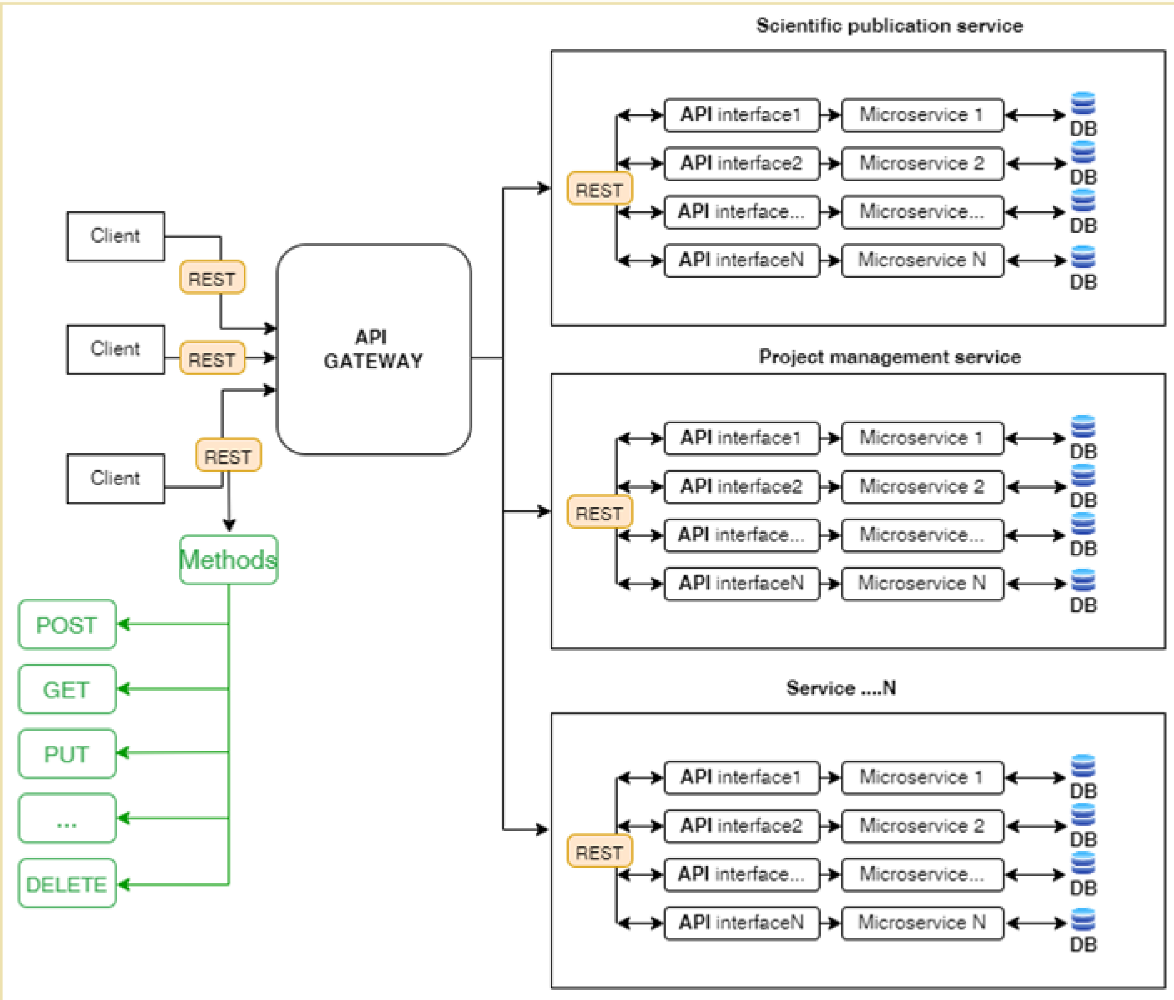

Figure 2 Microservice Architecture Diagram of the Digital Educational Ecosystem

Let us consider the key features and advantages of microservice architecture for creating a digital educational ecosystem, based on existing positive experiences:

- *Flexible scaling:* When the load increases, new service instances are deployed in the cluster, which reduces the load [27].
- *Independent deployment:* Microservices are independent, autonomous modules that can be deployed and updated separately, allowing efficient management of digital educational environment functions, accelerating the adaptation and introduction of new features. This modular approach simplifies updating and scaling the system, enhancing its overall flexibility and stability.
- *Technological flexibility:* Microservice architecture allows each individual service within the digital educational ecosystem to be developed in any programming language using various tools. Specialist groups are formed for each task, which increases the speed and quality of development, making the development process faster and more efficient [28].
- *High reliability:* Independent microservices do not affect one another; if one part fails, the entire application continues to function [29; 30].

Within this study, a prototype digital ecosystem for graduate students is being created, encompassing various tools, platforms, and resources. This will enable the realization of its pedagogical potential, enhance the educational experience, provide conditions for scientific activity, promote collaboration with peers, and facilitate interaction with university and professional scientific communities. The functionality of the digital ecosystem to stimulate research and innovation activities among graduate students was defined during previous research [4].

Let us examine the capabilities of the digital educational ecosystem in greater detail, presented in the table, focusing on its structure and the key functions of each service that realize its pedagogical potential. It is important to note that the services represent elements that organize the functionality of the main application, providing services and opportunities for users.

Table 1

Functional Characteristics of Services in the Digital Educational Ecosystem for Graduate Students' Research Activities

№	Service Name	Main Functions of the Service
1	Data Visualization Systems	Data visualization, interactive reports and dashboards, integration with data sources, real-time analysis, chart and graph support, data customization and filtering, data import and export, automatic updates, and collaboration.
2	Machine Learning and Artificial Intelligence Tools	Creation and training of neural networks, compatibility with machine learning tools and libraries, machine learning algorithms, compatibility with Azure services and tools, use of TensorFlow and other machine learning libraries.
3	Library Information Systems for Scientific Publications	Publication search, full-text access, creation of personal collections, subscription to new article notifications, search result filtering and sorting, access to metadata, and support for various data export formats.
4	Information Systems for Research	Creation and management of surveys and data forms, support for multi-stage surveys and branching logic, integration with different systems and databases, report generation, and real-time data collection and analysis.
5	Scientific Communication Information Systems	Sending and receiving messages, contact management, group chats, file sharing, video conferencing, audio and video messaging.
6	Project Management Information Systems	Project planning, task management, coordination and communication, progress tracking, documentation creation, reporting and analytics, system integration, access configuration, and collaboration support.
7	Big Data Analysis Software	Big data processing and analysis, storage, integration with other systems, use of visualization tools, support for various data formats.
8	Grant and Scholarship Information Systems	Funding opportunity search and filtering, application submission, information management, analytics and reporting, integration with other systems.

9	Electronic Portfolio Systems	Portfolio creation, multimedia and language support, achievement display, integration with educational and professional platforms, analytics, and reporting.
10	Electronic Publication Systems	Application submission, article publication, assessment and review, integration with other systems.
11	Software for Creating and Presenting Scientific Works	Creation of text documents using templates and styles, real-time collaborative editing, document and presentation creation using predefined templates.
12	Conference and Symposium Information Systems	Registration, application submission, program management, virtual conference organization, reporting and analytics, integration with external services and databases.
13	Specialized Information Systems and Databases	Data storage, management, search, and access; integration with other systems, data analysis, and protection.
14	Virtual Laboratories and Simulation Environments	Creation of virtual experiments, simulation of physical processes in a virtual environment, data display as graphs, animations, and 3D models, collaborative work, emulation of various conditions, integration with other systems.
15	Anti-Plagiarism Systems	Text comparison, LMS integration, multi-language support, data protection.

The architecture of the "Project Management Information Systems" service is shown in Figure 3. As seen in the model (see Fig. 1), each business function is implemented as its own microservice, allowing for the "Project Management Information Systems" service to expand functionality by introducing new business functions. Each microservice has its own technology stack and database, selected to best fit specific tasks.

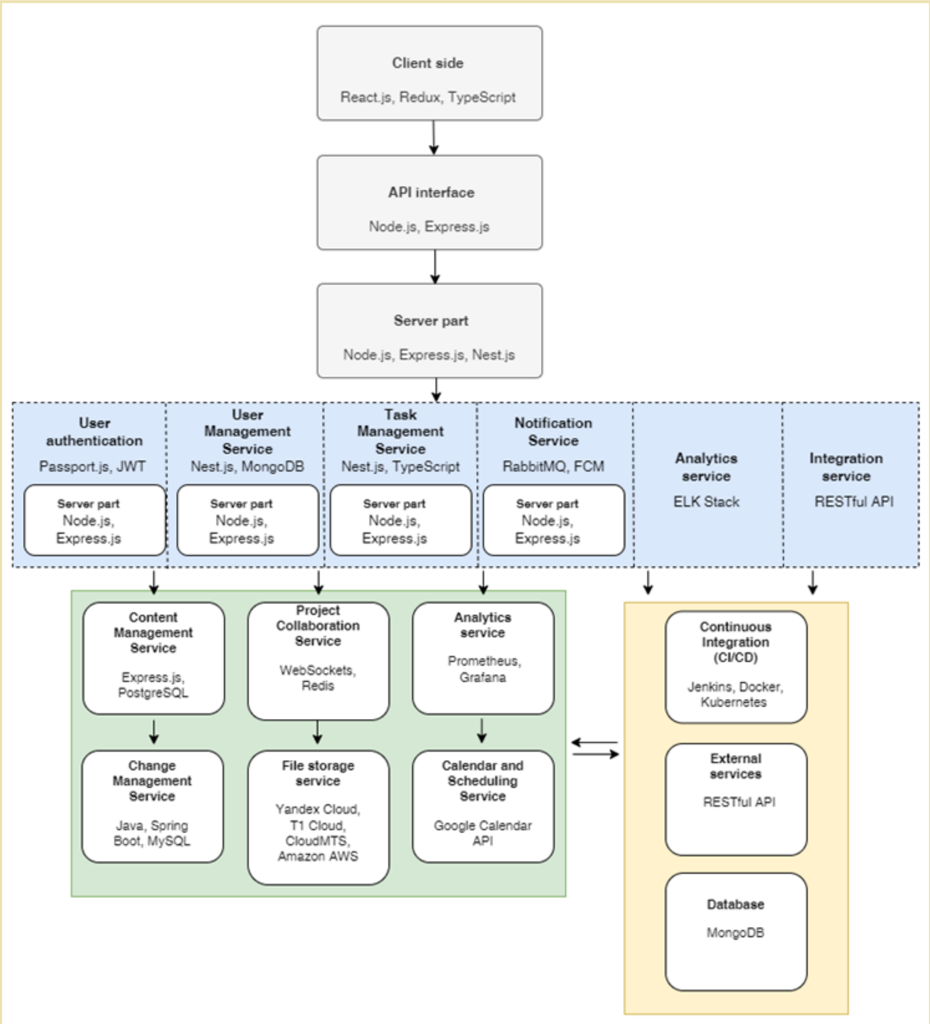

Figure 3 Architecture of the "Project Management Information Systems" Service

The choice of technologies and databases in a microservice architecture is driven by the specific needs of the project, team capabilities, as well as performance, security, and scalability requirements. Node.js is frequently used for its high performance, unified language for both client and server sides, and a wide variety of frameworks and libraries. MongoDB was chosen as the database for its flexibility in handling unstructured data.

Let’s examine the architecture of the task management microservice. The client-side system is developed using React.js, a library for creating dynamic and responsive interfaces thanks to its component-based architecture and virtual DOM. Redux is used for application state management, ensuring predictability and ease of tracking. The API acts as a central element, receiving client requests and directing them to the relevant microservices, ensuring security and load balancing across services.

The server side is developed using Node.js and Express.js – a framework that simplifies creating server applications on the Node.js platform. The server architecture is layered and includes multiple levels: the controller layer processes incoming HTTP requests and sends responses to clients; the service layer includes business logic, performs data validation, and manages interactions between controllers and repositories; the repository layer is responsible for database operations; and the data access layer uses ORM model technologies.

Since in a microservice architecture, each service or module typically operates with its own database – its type defined by the tasks and data the service will handle – the PostgreSQL technology was selected.

Let’s build an ER diagram of the task management service database. PostgreSQL is an open-source object-relational database management system (DBMS) known for its high reliability and performance, supporting transactions and complex queries. The presented design (ER diagram) of the database is optimized for a task management system, where each table reflects key entities of the system, such as users, projects, tasks, task assignments, comments, and attachments.

As a result, a prototype digital ecosystem for graduate students has been developed. This ecosystem plays a key role in supporting research activities, providing convenient and innovative tools for collaboration and knowledge sharing. It also creates conditions for skill development and successful completion of research and innovation projects. Figure 4 shows the user’s personal account in the digital ecosystem with available services. The services are thematically divided and represent independent digital tools implemented using various programming languages and technologies. Upon navigating to a thematic section, the internal functionality of the available service is provided. If a user requires the functionality of an external service, they can connect it independently. Popular applications are integrated into the system using APIs, enabling an intuitive user experience within the digital ecosystem. Thus, the graduate student independently configures their workspace and manages the necessary services.

Let’s consider the “Project Management Information Systems.” Graduate students have access to an internal project management platform designed according to modern requirements and standards. This platform includes numerous tools and features that enable planning, organizing, and monitoring the execution of projects of various complexities. Graduate students can independently connect available project management services, whose functionality is integrated via API. All project management services have functionality integrated through the API, ensuring seamless interaction and data synchronization between different services, which significantly optimizes the student's work.

One of the essential functions of the service is project planning. Users can create and customize project plans, set goals, tasks, and deadlines. The service allows users to create tasks and subtasks, assign them to specific team members, and set priorities and deadlines. Users can monitor task statuses and receive notifications about upcoming deadlines. Constant communication is maintained between project participants through communication and information-sharing tools. Features for uploading, storing, and managing project documentation in a single place are implemented, ensuring that all team members have access to the latest information. Thus, the project management service aids in planning, organizing, and monitoring project progress, ensuring transparency and control at all stages and promoting effective collaboration among team members.

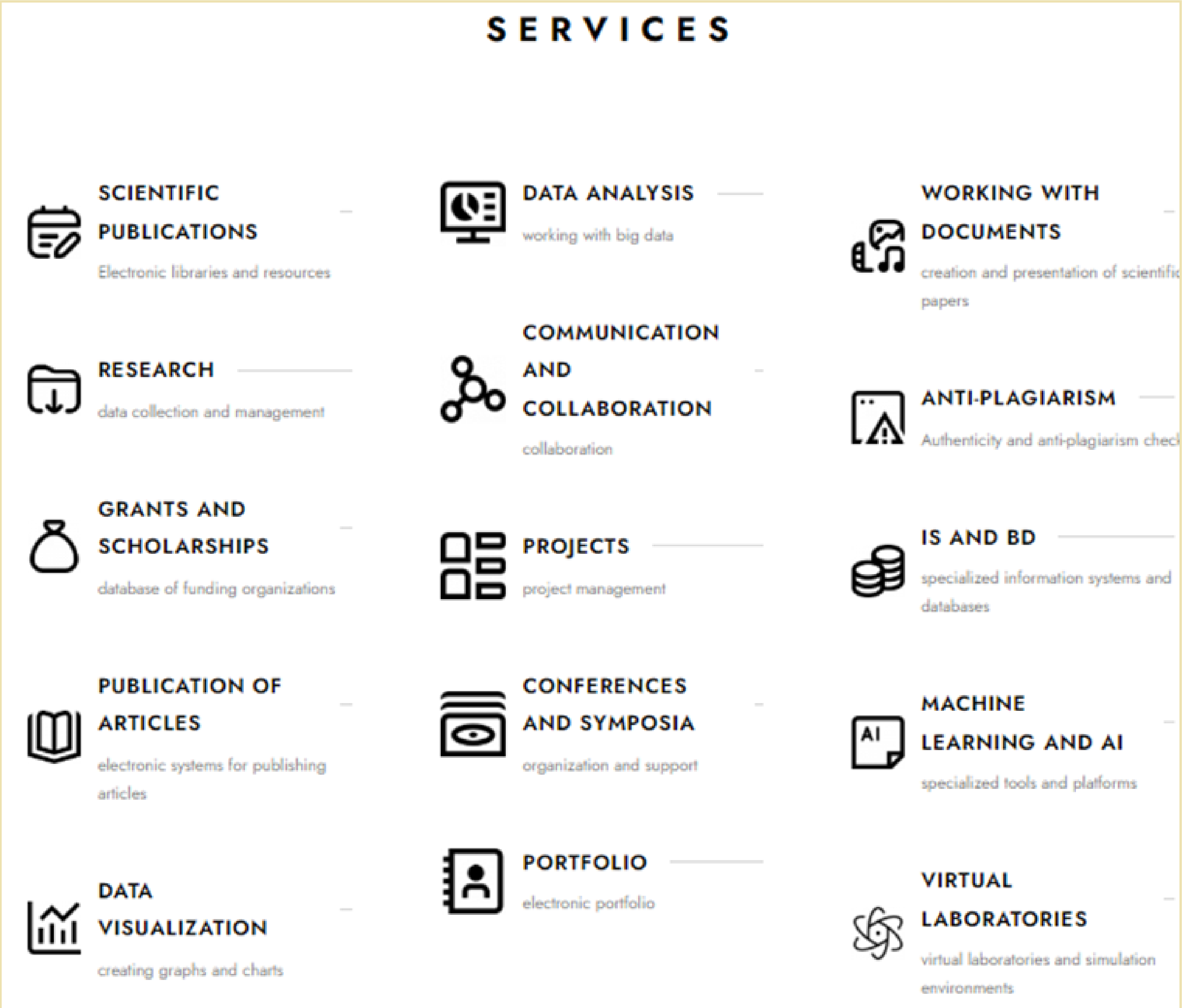

Figure 4 Services Section in the User's Personal Account

Preparing the system for operation (making adjustments) involves implementing necessary changes for the smooth functioning of the digital ecosystem. This stage is crucial as it addresses issues identified during testing, which helped detect errors and disruptions in the trial phase. Implementing adjustments will ensure stable system operation and help minimize and prevent potential future issues when using the system. The adjustment process is labor-intensive and can be quite lengthy.

DISCUSSION OF RESULTS

We agree with N. Alsufyani and A. Q. Gill [13] that "the digital ecosystem is viewed as a network of interconnected organizations, people, and entities collaborating to co-create value." Studies by X. Xue and G. Li introduce a new approach to building a digital ecosystem based on swarm intelligence [14], representing reliable, scalable, and self-organizing behavior for working with dynamic systems [15].

The need to develop a prototype of a digital educational ecosystem arises from the requirement to support the educational process through interconnected digital platforms, resources, and tools [4].

Testing the current digital ecosystem prototype in practice required addressing the task of refining key organizational and pedagogical conditions for its use in preparing graduate students for research and innovation activities, specifically:

1. Inclusion of access to modern digital infrastructure for research activities in the digital ecosystem: access to high-speed internet, modern computers, software, and technical tools for working with scientific data and resources. Graduate students can more readily find relevant information, conduct research, participate in scientific conferences and seminars, publish their work in scientific journals, and use other technical means, such as specialized equipment for measurement, data collection and analysis, visualization tools, etc.

2. Inclusion of seminar and conference organization capabilities in the digital ecosystem: holding regular events where graduate students can exchange experiences, present their research, and find partners for joint projects.

3. Inclusion of opportunities for assigning an experienced academic advisor to graduate students and online communication tools: providing consultations on setting up experiments, data processing, and research result analysis.

4. Inclusion of tools for organizing graduate students' access to financial support for research: ensuring access to grants, scholarships, and scientific project competitions that can foster interest in scientific activities and provide financial support.

5. Inclusion of access to online and virtual scientific laboratories and research centers: equipping specialized rooms and equipment for conducting research and providing support from experts in various fields.

6. Provision of mentoring support from university leadership: encouragement and support for graduate students' activities in science and innovation, creating conditions for their self-development and professional growth.

CONCLUSION

The creation of a functional prototype of the digital ecosystem for graduate students' research activities involved refining the conceptual framework based on the impact of new trends in the information technology sector and an analysis of positive practices in other fields. Based on the new foundation and previously identified emergent properties of the digital ecosystem, reinterpreted in the context of pedagogical science, the pedagogical potential of digital educational ecosystems was substantiated. This, in turn, enabled the determination of the structure, technology, and content of the elements of this ecosystem and justified the use of microservice architecture with the desired properties. This architecture choice simplified development, testing, and maintenance, which is especially important for companies operating in a highly dynamic market environment with rapidly changing requirements.

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