frontiers | Frontiers in Education

TYPE Technology and Code
PUBLISHED 09 February 2024
DOI 10.3389/feduc.2024.1291831



OPEN ACCESS

EDITED BY
Clifford A. Shaffer,
Virginia Tech, United States

REVIEWED BY
Mohammad Najib Jaffar,
Islamic Science University of Malaysia, Malaysia
Andreia de Bem Machado,
Federal University of Santa Catarina, Brazil
Suresh M,
Amrita Vishwa Vidyapeetham University, India

*CORRESPONDENCE
Yurii Andrashko
✉ yurii.andrashko@uzhnu.edu.ua

RECEIVED 10 September 2023
ACCEPTED 26 January 2024
PUBLISHED 09 February 2024

CITATION
Biloshchytskyi A, Omirbayev S, Mukhatayev A, Kuchanskyi O, Hlebena M, Andrashko Y, Mussabayev N and Faizullin A (2024) Structural models of forming an integrated information and educational system "quality management of higher and postgraduate education".
*Front. Educ.* 9:1291831.
doi: 10.3389/feduc.2024.1291831



# Structural models of forming an integrated information and educational system "quality management of higher and postgraduate education"

Andrii Biloshchytskyi[1,2], Serik Omirbayev[1], Aidos Mukhatayev[1,3], Oleksandr Kuchanskyi[4], Myroslava Hlebena[5], Yurii Andrashko[5]*, Nurken Mussabayev[6] and Adil Faizullin[7]

[1]Astana IT University, Astana, Kazakhstan, [2]Department of Information Technologies, Kyiv National University of Construction and Architecture, Kyiv, Ukraine, [3]Higher Education Development National Center, Astana, Kazakhstan, [4]Department of Computational and Data Science, Astana IT University, Astana, Kazakhstan, [5]Department of System Analysis and Optimization Theory, Uzhhorod National University, Uzhhorod, Ukraine, [6]Department of Digitalization of Education, Abai Kazakh State Pedagogical University, Almaty, Kazakhstan, [7]Department of Strategy and Corporate Governance, Astana IT University, Astana, Kazakhstan

The study examines the design of an information and educational System for quality education management. The requirements for the information environment of universities are formulated. The delineation of distinct stages in the technological process for shaping the values of information objects is outlined, achieved through the execution of information procedures. These procedures generate a technologically comprehensive product applicable within the university context. A set of heterogeneous systems for automating university activities makes obtaining integral characteristics based on information from different sources difficult. The research suggests an approach that allows you to get rid of the disadvantage. The introduction of an integrated information environment has been reviewed. To implement the information system "quality Management of Higher and Postgraduate Education," a conceptual model of the system architecture and a logical structure was developed. The developed information model was based on the model of a complex information and educational environment of a higher educational institution and the Ontological model of the database of the integrated information and educational environment. The preliminary results of the pilot implementation of the system in the activities of Astana IT University are summarized, which made it possible to improve the quality management of the educational process.

KEYWORDS

**information system, higher education, quality management, microservices, structural model**

## 1 Introduction

One of the fundamental components of the UN's sustainable development agenda for 2030 is ensuring quality education. A crucial element in achieving fair and inclusive education for all is the development of digital technologies, aimed at providing inclusive and equitable quality education for everyone. Digital technologies have become an important tool in achieving this goal. The creation of new technological tools has significantly changed education. Work by Haleem et al. (2022) describes the need to implement digital technologies in education and discusses the main areas of their application in education. The question of how to implement digital technologies in education can be answered by intellectual analysis of educational data and learning analytics. The peculiarities of using such tools for planning the educational process are described in work by Kostopoulos and Kotsiantis (2022).

The introduction of new learning tools was a critically necessary task during the COVID-19 pandemic. Home-based learning became a common process. However, remote and blended learning technologies have significant problems in implementation and use. In online learning environments, students face various difficulties, including due to weak feedback. Creating content for such learning is a complex process that requires, among other things, a lot of time resources. This content must also be adapted for disabled students. Work by Seale et al. (2015) describes the features of applying digital technologies for such a category of students, which corresponds to the strategy of ensuring quality inclusive education. Work by Tohara et al. (2021) describes the features of applying AR technology for planning education for disabled students.

Digital technologies in education have led to the emergence of various Learning Management Systems (LMS). These systems facilitate virtual classrooms, enabling real-time interaction between teachers and students. Teachers can share resources, conduct lectures, assess students' knowledge, gather feedback, and address inquiries. In work by Pinho et al. (2021), a quantitative study was conducted with a survey of students from Portuguese universities, resulting in 631 valid responses. The obtained results show that the characteristics of the LMS Moodle, as proposed by the theory of diffusion of innovations and personal innovativeness in information technologies, positively influence the use of this tool for achieving educational goals.

Educational resources are now accessible around the clock, 7 days a week. The implementation of cloud storage, video recording of lectures, and the availability of electronic notes have empowered students to access resources at their convenience. According to the findings obtained in work by Shohel et al. (2021), the blended model of teaching and learning allows students to learn freely, demonstrate their knowledge in various ways, and develop important knowledge and skills.

The process of optimizing education is extensively studied in the theoretical aspect. In particular, the paper by Zunimova et al. (2023) describes developing a model for optimizing distance learning. An information-logical model of distance learning optimization has been developed. This model implies the organization of the educational process in such a way as to strengthen the weaknesses of students, reveal their potential, and focus on the comprehensive development of knowledge and skills.

The management of reporting and tasks has changed significantly; instead of creating actual timesheets that can be sent home once a semester. Now, teachers can assign, collect, and evaluate work using specialized learning management systems, informing students and parents about their progress (Nuere and De Miguel, 2021). Research by Cabero-Almenara et al. (2021) shows that the degree of digital competence of higher education teachers following the DigCompEd system from different fields of knowledge and all ages differs significantly.

The significance of extensive data and analytics in education has been a crucial yet sometimes overlooked aspect of educational technology. Educational institutions recognize the importance of comprehensive data on the performance of both students and teachers, especially as they increasingly utilize virtual classrooms, e-learning platforms, and online examinations. The research results described in work by Lewis et al. (2013) provide useful information about the frequency of digital technology use, as well as the important factors that influence their implementation in the educational process.

The advantages of using information and communication technologies are undeniable. However, employing such technologies poses several challenges regarding management and quality control of training. Faced with the intensification of global competition in the field of education, universities and other higher education institutions are implementing Total Quality Management (TQM) to stay ahead of competitors. Work by Nasim et al. (2020) describes the features and limitations of applying TQM in higher education and the possibilities for further development in this direction. Apart from the traditional TQM method (Hill and Taylor, 1991), the Quality Function Deployment (QFD) method (Raharjo et al., 2007) and the Lean Six Sigma (LSS) method (Antony, 2014) are also used in higher education institutions to ensure quality. Each of these methods contributes to transforming education in accordance with Quality 4.0. Specifically, work by Alzahrani et al. (2021) provides an assessment of the higher education environment across 11 axes of the LNS Research Quality 4.0 research quality system and offers a vision for ensuring educational quality in the context of digital transformation.

Quality assurance is an everyday activity all over the world. National quality assurance agencies and university departments manage quality assurance. Research identifies the main obstacles to quality. Work by Cardoso et al. (2016) identifies the primary obstacles to quality as perceived by Portuguese researchers. Analysis shows that researchers tend to view these obstacles as mainly related to the structural component, including the functioning of institutional management. However, it should be noted that not all researchers and university staff have a good understanding of the management structure and strategic goals of the university.

The paper by Kuchansky et al. (2022) describes a conceptual device for forming information spaces for performers of educational projects in a dynamic environment. The research hypothesis that educational project performers' progressive, dynamic development affects these projects' potential is experimentally tested. However, this study considers only one scientific component of the university's activities and does not consider others. In paper by Biloshchytskyi et al. (2021), the apparatus necessary for the formation of information spaces of subjects of scientific activity was further developed. Multiple models of identification of collective and individual subjects of scientific activity have been developed. The conceptual scheme of interaction between collective and individual subjects of scientific activity is described, taking into account the dynamics of their productivity. The gap in this study is in the part of the educational process.

Applied information technology for planning and administrating educational environment management can be carried out based on Project-Vector methodology (Biloshchytskyi et al., 2018). The proposed method is recognized as a means to compensate for the impact of unforeseen situations on the implementation of projects of subjects of educational environments.

It can be concluded that currently there is no single standard for an integrated system for monitoring, organizing, and supporting the quality of the educational process. That is why the development of such a system involves conducting scientific research at the planning stage and constructing a conceptual scheme.

The study aims are to develop and design an information and educational system for quality education management.

## 2 Materials and methods

The information system "quality Management of Higher and Postgraduate Education" is being developed and implemented to support and improve higher education in Kazakhstan following the principles of the Bologna Process, which began in Europe in 1999 and is aimed at creating a common European higher education area.

Before the development of this system, data on monitoring the implementation of mandatory, recommendatory, and optional parameters of the Bologna Process by higher educational institutions of the Republic of Kazakhstan were collected manually using Microsoft Excel and subsequently processed and analyzed by employees of the RSE at the National Center for the Development of Higher Education of the Ministry of Education of the Republic of Kazakhstan—a subordinate organization of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

Unfortunately, Excel was inefficient due to:

- limitations on the amount of data it can process;
- high probability of errors such as typos, incorrect formats, and duplicates;
- lack of a sound version control system and a history of data changes;
- limitations of analytical functions, creation of complex and informative data visualizations compared to more advanced data analysis tools such as Power BI or Qlik;
- Lack of flexibility in automating complex data processing processes.

Therefore, within the framework of the program-targeted financing project, the development of an information system has begun, which is designed to improve the quality of data collection from all information systems of organizations of higher and postgraduate education of the Republic of Kazakhstan and provide the state authorized bodies of the Republic of Kazakhstan with analytical and other digital tools for the implementation of the following tasks and functions:

- Harmonization of higher education: unification of the structure and system of higher education in Kazakhstan with European standards. This includes the development of common standards and criteria for assessing the quality of education to strengthen the implementation of student-centered learning;
- Support for academic mobility: One of the main objectives of the Bologna Process is to facilitate the academic mobility of students, scientists, and teachers between institutions of higher education in different countries. Analytical tools should facilitate structuring international mobility programs in higher education, which should be implemented to promote diversity, equality, and inclusiveness. They should, in particular, facilitate the participation of students and staff from vulnerable, disadvantaged, or underrepresented segments of the population.
- Development of the quality of education: to promote the introduction of modern teaching methods of the Ministry of Education and Science of the Republic of Kazakhstan and to contribute to the continuous improvement of teaching, as well as practical assessment and monitoring of accreditations of higher education institutions of the Republic of Kazakhstan and their educational programs following the standards and guidelines for quality assurance in the European Higher Education Area (ESG).
- Information support: Provide information and analytical support to ensure community participation in the development of higher education that promotes diversity, equality, and inclusiveness, as well as strengthen the university's capacity to improve the effectiveness of teaching and learning.

The developed information system "quality management of higher and postgraduate education" consists of several microservices. The system interface is made in the JavaScript programming language using the Vue.js framework. The microservices of the system are developed in the PHP language using the Laravel framework. The system was launched on a server running the Linux operating system using Docker technology. More details with the project in the repository.[1] Materials are distributed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International Public License.

To investigate the effectiveness of the proposed and developed information system "Quality management of higher and postgraduate education," it was decided to conduct a pedagogical experiment at Astana IT University.

In this experiment took part more than 500 teachers and more than 5,000 students in the "Computer Science" field, 10 educational programs at the "Bachelor's" educational level, seven educational programs at the "Master's" level, and two educational programs at the "Doctor of Philosophy" level.

## 3 Results

### 3.1 The requirements for the information environment of universities

Following the purpose of the study, the requirements for the information environment of universities are formulated.

At the present stage, the information environment has turned from a means of providing access to the necessary information into an obligatory component of the university management infrastructure and a set of intellectual services, without which it is impossible to imagine the organization of management and training in universities today.

Considering the peculiarities of universities as an object of informatization, the Comprehensive information and educational

1 https://github.com/Nurkhan01/balonskiy

environment (CIEE) of universities should meet some requirements for the main characteristics that are important for management tasks:

#### 3.1.1 Completeness of the data

For management tasks, the data necessary for analysis and decision-making must fully reflect the analyzed process's performance indicators. To ensure this property of information, the CIEE of the University must cover all the necessary areas of activity of the university, and the data in different areas should be interconnected. Hence, there is a need to ensure the integration of corporate data.

#### 3.1.2 Reliability

For the information to be reliable, it is necessary not only organizational solutions to ensure data entry but also specific mechanisms at the CIEE level. The correctness of the data can be verified, firstly, with the help of specialized checks when entering data, secondly, by automated data matching procedures when generating reports, and thirdly, with the help of users of the environment receiving the same data in various applications, which increases the probability of detecting input errors. The more users, services of the environment, and the intensity of work, the higher the probability of detecting errors and eliminating them.

#### 3.1.3 Relevance

To ensure the relevance of data in the CIEE, relevance procedures are necessary, which can only be built in conditions of full data integration.

#### 3.1.4 Consistency

A specific set of rules provides consistency of information:

- Initial data entry into the CIEE is carried out only in one application;
- Primary data can only be stored on its primary server, from where it can be replicated to other applications. Changes to this data are possible only on the primary server. The consequence of this rule is the need to have uniform reference books for all applications of the CIEE.

#### 3.1.5 Security and data access management

The support of regulated managed access is possible if there is a registration system in the CIEE with access rights to all information resources of universities. All CIEE projects should be cataloged, and roles should be assigned to staff and students depending on their responsibilities at universities. A comprehensive solution to the problem of managing access to data and services of the CIEE is possible based on creating a unified registration and access control system for all CIEE projects. The security of work is ensured both at the hardware level and at the level of the rights management system and the protocols used.

#### 3.1.6 Efficiency

CIEE performance is an essential factor in making informed decisions on time. Different approaches achieve performance improvement. The CIEE architecture should be based on a component model that allows distributing components across servers and using load balancing algorithms to transfer work or data to a less loaded server.

#### 3.1.7 Stability

The stability of the CIEE is understood as the ability to resume the operation of applications and services in a given time interval after failures in the operation of hardware or software. The stability of the CIEE should also be ensured at the level of specialized procedures for verifying and restoring data integrity. The basics of the component model of the information environment are given in.

The CIEE should ensure:

- availability of a single database;
- one-time data entry with the possibility of their subsequent editing;
- data usage mode by many users at the same time;
- differentiation of data access rights;
- using the same data in different applications and processes;
- the ability to exchange data between different applications without performing import operations.

The technical infrastructure of the CIEE universities consists of:

- computer equipment (computer classes, separate computers, dedicated server);
- peripheral and projection equipment (printers, scanners, projectors, etc.);
- telecommunication equipment (modems, routers, etc.);
- corporate computer network;
- system and specialized software.

Thus, the CIEE of universities is a set of concretized data and knowledge elements that are an information resource of universities and cover many sets of objects related to subsystems of education, scientific research, educational process management, etc. The constituent elements of the CIEE are objects, so the CIEE of universities can also be considered as a set of objects that make up the CIEE.

The CIEE object is a complete set of data and knowledge suitable for use as an integral information resource.

The objects of the CIEE include software tools, information base and its elements, information on complex media (documentation, instructions, etc.), methodological developments, textbooks, etc., information, and curricula.

Relative to each other, objects can be parent (contain objects) or child (belong to another object). Objects have a shell (the form of filling) and a content (the object's content, the filling itself).

Considering the existing realities, the CIEE can be divided into several functional areas (machine—non–machine, internal–external, management—educational process).

1. Depending on the source of information about universities:

a. internal information resources, that is, arising in the university itself;

b. external information resources, i.e., arising in other subjects of the economic and legal environment that are not part of universities.

2. From the way information is presented, i.e., actually from the information carrier:

a. machine information resources, i.e., stored electronically;

b. out-of-vehicle, that is, presented on a solid carrier.

3. Depending on the field of information used at the university:

a. information resources of the management system, that is, information used by the service units of universities;

b. information resources of the educational process, that is, information used in the educational process.

Taking into account the understanding of the CIEE as a set of information areas of different origin and functional purposes, it is possible to visually reflect the CIEE in the form of a three–dimensional figure - the mental space of functional areas (Figure 1), where functional areas mean the classification elements themselves.

Consider an intricate information and educational milieu within universities, encompassing an array of information objects utilized in the endeavors of university departments and personnel. Additionally, envision information procedures designed to facilitate the creation of these objects.

Definition 1: An information object is a set of information resources capable of meeting the information needs of an individual subject or subjects of higher education institutions and providing a solution to some functional task.

The totality of information objects is represented as a set

$$U = \{u_k\}, k = \overline{1, y}$$

The Comprehensive Information and Educational Environment (CIEE) objects are sourced from various other objects and entities within universities, as illustrated in Figure 2. The external environment is also engaged, exerting influence on and being influenced by the educational processes.

The creation of information object values can be viewed as a distinct procedure. Information transformation procedures establish connections between different information objects. These procedures are recommended for implementation once the values of all relevant input attributes of the procedure's information objects have been generated.

Definition 2: Information procedure ($Z = \{z_j\}$) refers to a set of prescribed actions executed either on a hard drive or within the algorithmic framework of software tools. These actions are designed to facilitate the transformation of information within a complex information environment.

$$z_j = \langle f_{j1}, f_{j2}, ..., f_{js}, \ldots f_{jn} \rangle,$$

where fjs—involves converting the information resource of a procedure into an information product of the same procedure.

The creation of values for individual information objects can be viewed as distinct procedures. Information procedures essentially serve as interfaces connecting various information objects. Each object possesses a set of information transformation procedures, each with several properties that dictate the speed of information processing and the level of significance of the initial information for educational and learning processes.

The information procedure delivers a technologically comprehensive information product that finds application within the university.

The stages of the technological process of forming the values of information objects will be presented by implementing information procedures.

Under the complex information and educational environment of universities, we will understand the formal three:

$$\text{CIEE} \subset \text{K} \times \text{I} \times \text{T},$$

In this context, K represents the functional tasks of universities, I represents the information content of these functional tasks, and T symbolizes the technology employed for populating information objects to address these functional tasks.

Subsequently, the Complex Information and Educational Environment (CIEE) of universities encompasses both information objects and information procedures that adhere to the structure of information processing technology within university services. The pivotal role in executing information procedures is undertaken by specialists within university services.

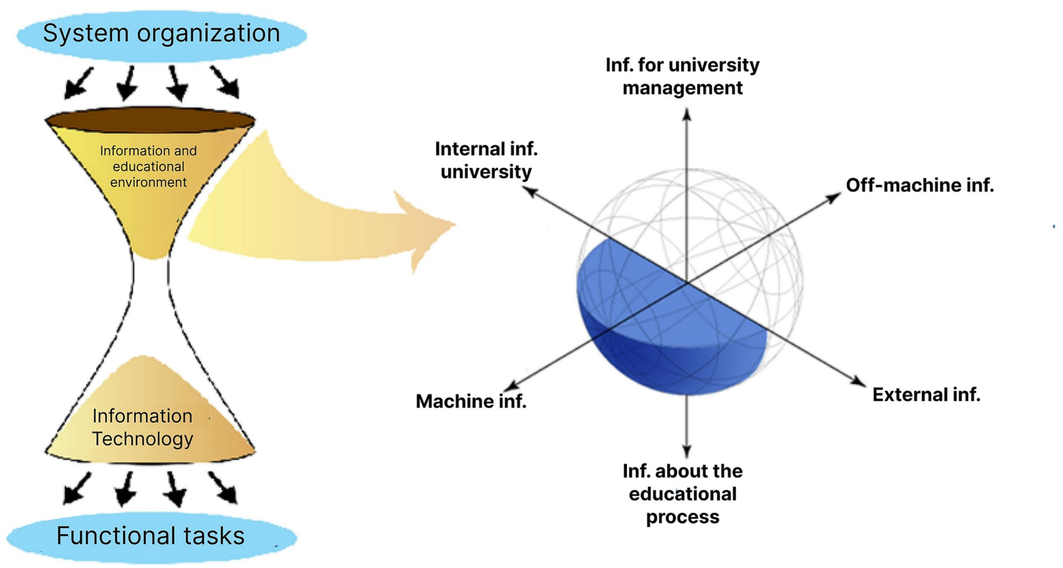


FIGURE 1
Integrated information and educational environment of universities.

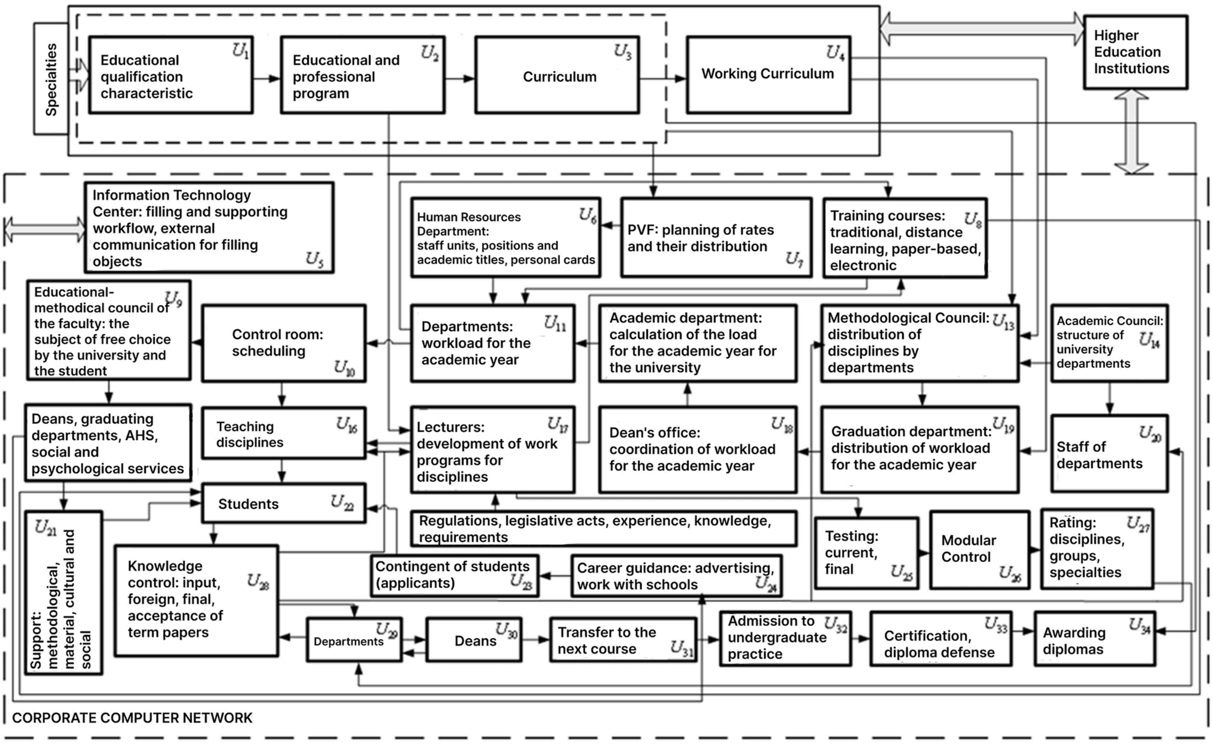


FIGURE 2
The scheme of interaction of objects of the information and educational environment of the educational process management system.

Prior to reaching decisions within the scope of a university's functional tasks, it is imperative to designate (populate) information objects. The values attributed to information objects are crafted within university services, drawing upon normative and methodological documents. This process involves the intellectual capabilities of specialists, software tools, and formal procedures for processing information.

Data filling for information objects within the Complex Information and Educational Environment (CIEE) is facilitated through the implementation of a system of information processing procedures within university departments. The structure of links is established based on the sequence of creating and utilizing the information resource within the CIEE. Consequently, the formal definition of the technology for populating information objects within the CIEE can be expressed as a pair: $T = <U, Z>$, where U represents systems of information processing procedures, and Z represents an information procedure.

To operationalize this technology, the establishment of an efficient information management framework within the functional departments of universities is essential. This approach will facilitate the development of highly effective university management systems by employing contemporary methodologies designed for complex organizational and technical systems. The implementation is carried out in the context of software and information management tools tailored to the specific needs of universities.

1. Collecting information involves obtaining data from documents received from external sources or from subjects involved in the university project management process.
2. Acquiring information relies on formal data processing procedures, software tools, and databases of standard management decisions, leveraging The knowledge and skills of university employees.

Each procedure can be implemented:

1. Through the execution of production functions by university service employees in a conventional (manual) mode.
2. When using software tools that implement appropriate methods and algorithms for processing information.

Each information procedure delineates specific rules governing the conversion of information object contents from one type into information objects of another type:

$$uz = zx(Uy), pz \in U, Uy \subseteq U, ux \in U.$$

One information procedure is implemented over other information objects to form one information object.

The combined set of information objects often contains subsets where filling them results in a new quality within a complex information environment. The attainment of the value uj0 through the implementation of an information procedure $u_{j0} = z_j(u_{j1}, u_{j2}, .., u_{jn})$ is only achievable with the values of information objects $u_{j1}, u_{j2}, .., u_{jn}$. Therefore, the entirety of information objects $u_{j1}, u_{j2}, .., u_{jn}$ establishes a new quality in the information environment—the quality of a community of action.

Now, the challenge is to develop a scheme for implementing information functions and procedures that guarantee the most effective creation of values (definition) for the information environment of university projects.

The implementation of an information system in an organization is a complex process, particularly when dealing with an integrated information system. The complexity arises from its comprehensive coverage of various departments and organizational units within an educational institution, each differing in functions and priorities. Considering this, it is essential to introduce a scheme for implementing an integrated information system that takes into account both the priority of the tasks and the time required for their implementation. It is assumed that the implementation should be efficient and quick, with higher-priority subsections included in the complex information environment first, regardless of the time needed for their information content. The goal is to find a method of implementation that allows for the rapid filling of information objects in the Complex Information and Educational Environment (CIEE) while ensuring its effective functionality as soon as possible, prioritizing the objects with the highest importance.

The task involves selecting the optimal sequence for filling Knowledge and Information Objects in the System of Complex Information and Educational Environment (KIOSK), taking their priority into account. This implies that the following conditions must be satisfied:

$$p_i > p_{i+1}$$

where $p_i$ is the priority of the i-th CIEE object.

To solve this problem, imagine a set of CIEE objects in the form of a graph G, with a set of nodes $VG = \{v_1 \ldots v_{i-1}\}$ which are the objects of the CIEE, and the set of edges of the EG are the processes of filling these objects with information. The weight of the arc is the priority of the end node belonging to this arc. The solution to this problem is divided into three stages:

Determining the priority values of i-th objects by the formula:

$$p_i = \frac{n_i}{N},$$

where: $n_i$ is the number of objects that can be filled after filling the i-th object; N is the total number of objects.

2. Select the source object from which we will start filling all other objects of the CIEE. Let a1 be the first of the possible j source objects (Figure 3). Let there be objects (there are many nodes on the graph $VG = \{v_1 \ldots v_k\}$), the filling of which is possible when filling a1, that is, there are many edges $EG = \{e_1, e_2, \ldots, e_k\}$, exactly the edge $e_1 = a_1v_1$, $e_2 = a_1v_2, \ldots, e_\kappa = a_1v_\kappa$, incident to the corresponding nodes of the VG set.

3. For each of the objects represented by $v_k$ nodes, there are many edges $E_kG = \{e_{k1}, e_{k2}, \ldots e_{kn}\}$, incident nodes $v_k$ and $EG \in E_kG$, that is, there is a set of n nodes $V_kG = \{v_{k1}, v_{k2}, \ldots v_{kn}\}$ such that they are also incident to the edges of the $E_kG$ and after filling which you can fill $v_k$. Then we calculate the weighting coefficient of the initial nodes $P_j$ as:

$$P_j = p_0 + \frac{1}{n_1} \cdot p_1 + \frac{1}{n_2} \cdot p_2 + .. + \frac{1}{n_k} \cdot p_k,$$

where: $p_0$ is priority of the start age; $n_1 \ldots n_k$ the number of nodes incident to the sets of edges $E_1G \ldots E_kG$, that is, the number of objects whose filling makes it possible to fill the given object represented by the node with data $v_k$; $p_1 \ldots p_k$ are priorities of the node $v_k$.

Calculating this formula for each of the possible $P_j$ source nodes, at the end we choose $P_j = \max$.

We take the CIEE filling as the initial object, represented on the graph by a node with the weighting coefficient of the initial nodes $P_j = \max$. After that, we apply the Prim algorithm to construct a minimal spanning tree (Prim, 1957).

We choose an edge l1 = b of maximum weight, which is incident to the initial node (a), and build a tree T1 taking $VT_1 = \{a,b\}$, $ET_1 = \{l_1\}$, m = 1 (Figure 4).

After that, among the edges connecting the vertices of this tree with the vertices of graph G that are not part of $T_m$, we choose the edge lm + 1 of maximum weight. We build a $T_{m+1}$ tree by attaching an edge $l_{m+1}$ to the Tm tree and its second node, which is not included in the $T_m$. We do this until the condition $m < i - 1$, is met, that is, until all the CIEE objects are filled.

The result of this algorithm will be a $T_m$ tree (V, E), which is the optimal sequence of filling all CIEE objects with data according to their priorities.

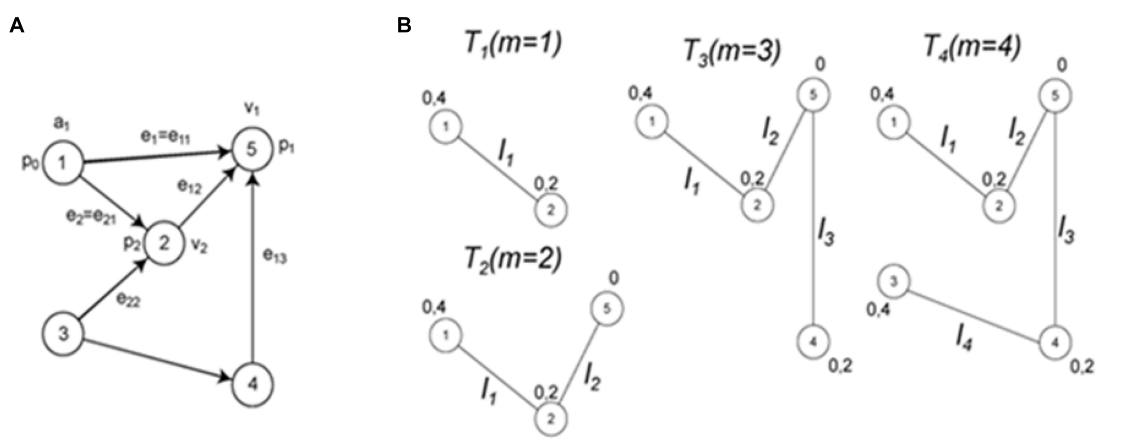


FIGURE 3
**(A)** Definition of the initial CIEE object for its filling. **(B)** The sequence of building a Tm tree representing the shortest way to fill a given set of objects. The numerical coefficients at the nodes are priorities and are calculated using the formula for determining the priority values of i-th objects.

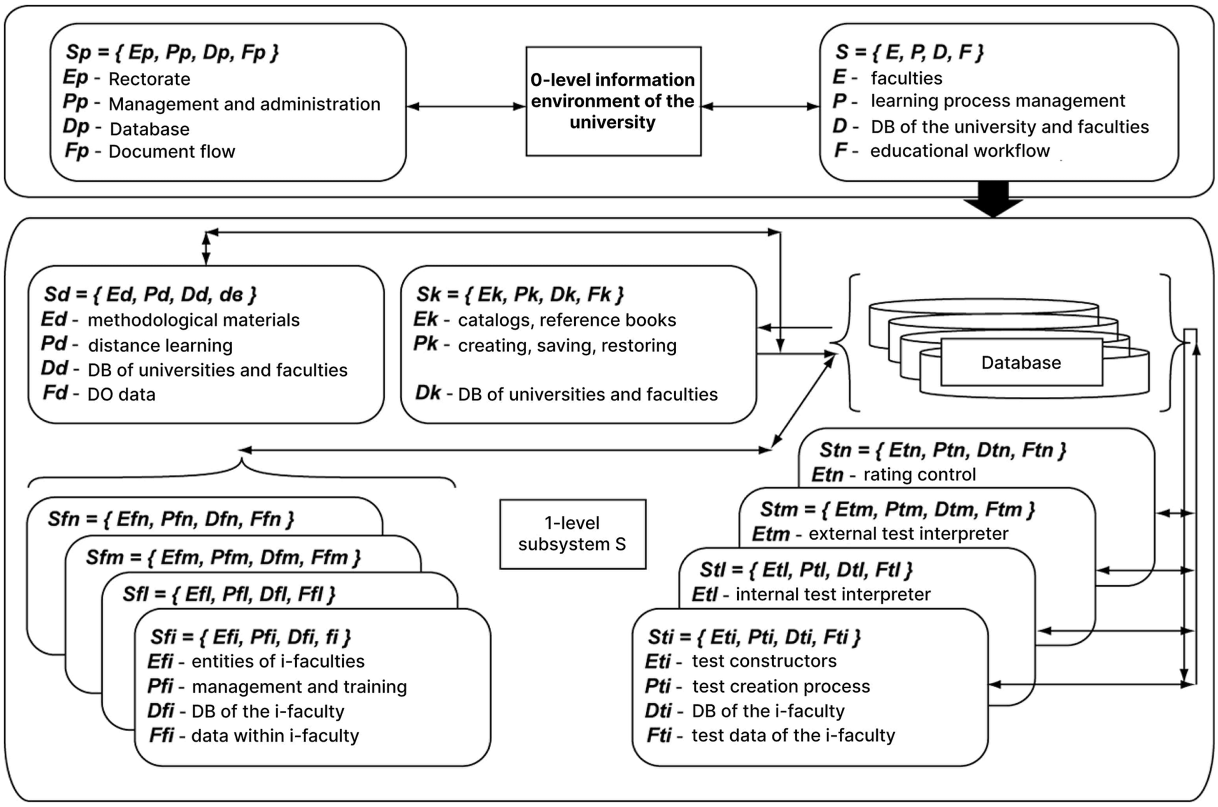


FIGURE 4
Structural model of the integrated information and educational environment of university.

## 3.2 A model of a complex information and educational environment of a higher educational institutions

Following the requirements formulated above for the information system, a model of the integrated information and educational environment of a higher educational institution is constructed.

The information infrastructure of the CIEE of universities is formed from:

- general-purpose software (text and graphic editors, spreadsheets, etc.);
- software for automating the activities of various services (for student accounting, personnel accounting, scheduling, performance analysis, library automation, etc.);
- software and methodological support for the organization of the educational process (educational and developmental computer programs, electronic reference books, multimedia encyclopedias, etc.);
- information resources of an educational institution (a single database, educational and methodological data banks, multimedia educational developments, a document repository, a WEB site).

A set of heterogeneous systems for automating university activities will not allow obtaining integral characteristics based on information from different sources to generate reports based on data from different systems. The approach that eliminates the above disadvantages is the introduction of an integrated (open architecture) information environment. As part of this approach, data from multiple sources are consolidated into a single data warehouse, creating the basis for the same display of different information and solving a wide range of tasks based on unified technological solutions. Then, the information environment will be able to optimize the management of the educational process and, first of all, control the quality of assimilation of the material.

The CIEE should provide access to the information users need at this moment and be a projection of universities' activities in the information technology field. Due to the innovative nature of the activities of universities, this requires the support of the information environment for the integration of processes.

To manage the information environment, it is necessary to use load-balancing mechanisms to achieve high performance and maintain the environment's reliable operation. It is necessary to use backup, archiving, and data recovery mechanisms to protect backups from unauthorized access.

Thus, a modern CIEE should be created as a single information space, a regulated system of relationships, where each user can and should supply and receive the necessary information collected on time and according to established schemes and rules. According to experts, it is only through a single information space that it is possible to increase the efficiency of information technologies and the use of information resources. Determining the directions of expanding information technologies, creating an infrastructure for implementing

CIEE, and defining database formats are the main tasks in creating a unified information space.

The information environment is a set of methods, tables, and links for entering, displaying, and analyzing information.

Currently, there are two main approaches to the design and development of CIOS: object-oriented and structural. The object-oriented approach is based on the object decomposition of the subject area, which is a collection of objects interacting with each other through the transmission of messages, and the structural approach is characterized by a general overview of the system and then detailing due to the decomposition of the system into subsystems and the hierarchical organization of these subsystems with an increasing number of levels. These approaches should not be opposed. They complement each other in the development of large systems.

In structural analysis, two groups of tools are mainly used, illustrating the functions performed by the system and the relationships between the data. Each group of tools corresponds to certain types of models (diagrams), the most common of which are:

- SADT (Structured Analysis and Design Technique) models and corresponding functional diagrams;
- In F In (Data Flow Diagrams) data flow diagrams;
- ERD (Entity-Relationship Diagrams) of the entity-relationship diagram.

The listed models together will give a complete description of the CIOS, regardless of whether it exists or is being developed.

Using the above-formulated requirements for building an information model of an automation object, the structural model of a university can be represented as a set of information-related processing subsystems.

$S = \{S_1, S_2, S_3, .., S_n\}$, based on a four a $S_i = \{E_i, P_i, D_i, F_{i.}\}$

where the set $E_i$ are external entities concerning this subsystem;

$P_i$ is a process or subsystem that converts input data streams into output streams according to a specific algorithm;

$D_i$ is an abstract storage for storing information (data drives), which is generally a prototype of a database;

$F_i$ is a data stream that defines the information transmitted through some connection from the source to the receiver, entities, and processes.

where the set is external entities in relation to the given subsystem;

Modern CASE tools (Computer Aided Software Engineering) provide continuous automation of such necessary stages of implementing complex information systems as modeling of domain processes, entities and relationships, iconological data structure, and creation of actual databases.

Using the proposed representation of the model as a set of separate subsystems, the CIEE of universities can have the form shown in Figure 5. The upper level of the hierarchy (level 0 in Figure 5) can be represented as a composition of information environments of two main subsystems: subsystems of management activities of universities and subsystems of learning process management and knowledge control.

For the CIEE to provide not only accounting functions but also support data processing and analysis, it is necessary to use reliable and scalable hardware and software platforms and technologies for various purposes - database management systems (DBMS), electronic document management systems (EDMS), Internet technologies, networks, distributed computing. Using information technologies in a single CIEE creates requirements for the architecture, which should be based on a component model and allow solving the problems of integrating applications developed based on various technologies.

The component model of the University's CIEE can best meet the requirements for the CIEE.

It has three main layers. The first is databases, possibly of different architectures. The second layer is the component layer, which, in most cases, is implemented based on web services, but other components can also be used (application servers, CORBA objects, DCOM objects). The third level is the application layer.

This approach makes the coexistence of various technologies, DBMS servers, and applications possible. Changes in the structure of one database do not lead to changes in the structure of many programs. Only changes are needed to the service responsible for the changed database. This makes it possible to simplify the process of developing and maintaining corporate software. A lot of attention in the CIEE is paid to data integration, in which databases are interconnected at a logical level.

The CIEE software of universities must meet the following requirements:

- work in network mode or provide the ability to run from the same server by different workstations;
- Store information in a single format available for processing by different programs or modules of the same software package or have data import functions;
- Be as compatible as possible and allow the connection of new modules;
- Provide multi-user mode and access rights differentiation.

The university's complex information and educational environment can be considered a set of databases and modules of specific users based on a motivational and functional approach.

## 3.3 Ontological model of the database of the integrated information and educational environment

The overarching objective of developing any model is to acquire information facilitating specific decision-making. However, the innate method of enhancing the informativeness of models through increased complexity and detail is constrained in practical application. For formalized systems surpassing a particular threshold of complexity, the granularity of the description and the practical utility of the information obtained tend to be conflicting characteristics.

To some extent, expanding the complexity of models and overcoming the complexity problem can be achieved by decomposing the complete model into submodels. The quality of these submodels can be evaluated before their integration into the overall system. Ultimately, a thoughtful breakdown of the complete model into components enables the construction of a functional system that delivers reliable information with an acceptable computational cost.

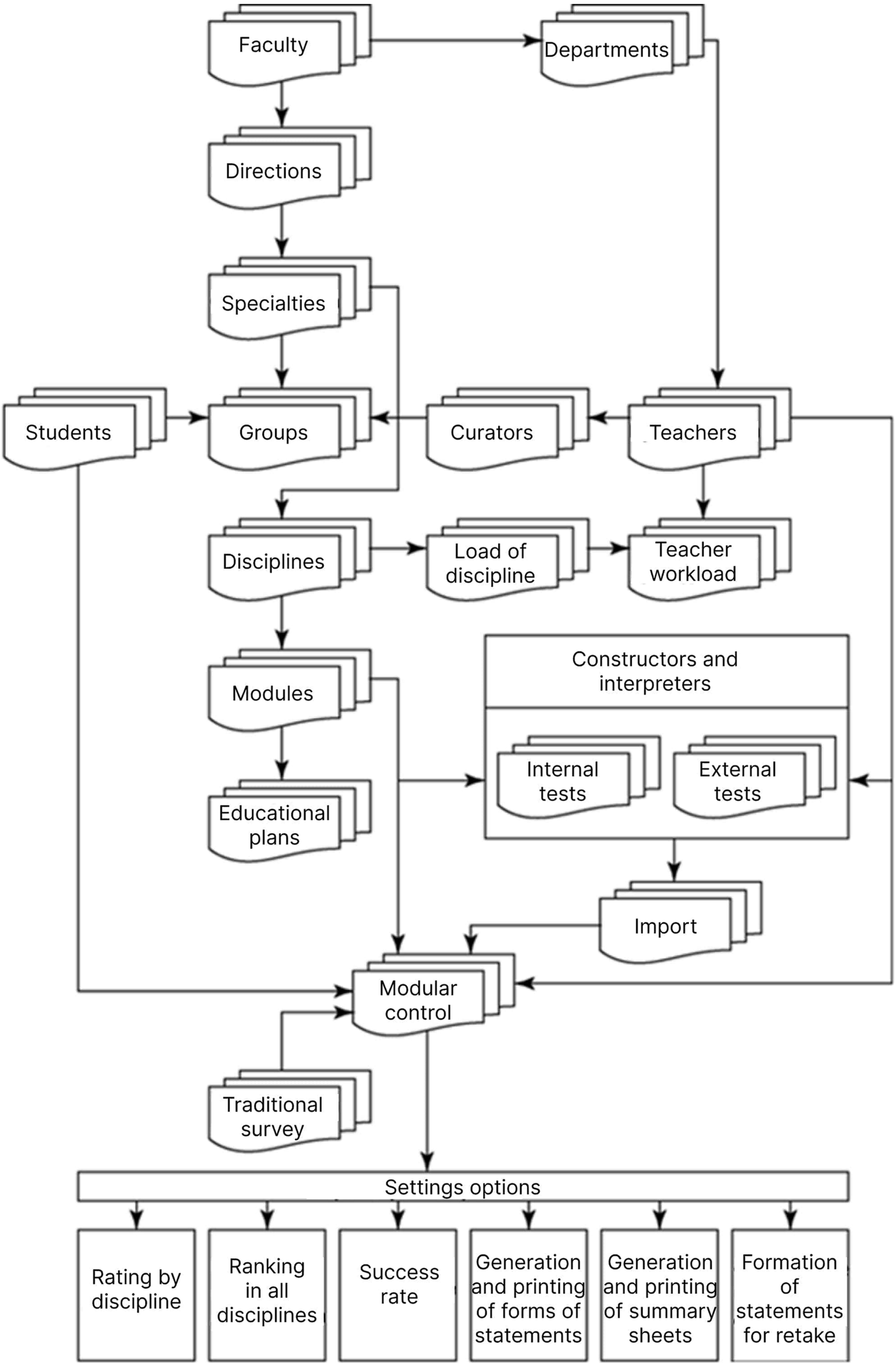


FIGURE 5
Structural model of the complex information and educational environment of the university.

## 3.4 Ontological model of the database of the integrated information and educational environment

The overarching goal in developing any model is to obtain information for making informed decisions. However, the natural approach of increasing model informativeness through complication and detail is practically limited. For formalized systems exceeding a certain complexity threshold, the level of description detail and practical value of the information obtained become antagonistic characteristics.

To some extent, it is possible to extend the boundaries of model complexity and partially address the complexity problem by decomposing the complete model into submodels. The quality of these submodels can be assessed before their integration into the overall system. Ultimately, a judicious breakdown of the complete model into components enables the construction of a functional system that delivers reliable information at a reasonable computational cost.

The domain ontology encompasses ontological concepts that are specific to a particular domain. These concepts mirror the fundamental properties, interconnections, and relationships among classes of real-world objects within that domain. The ontological context establishes the ontological binding of components, while the elements of the component specification articulate the concepts within the subject area and the relationships between them.

A practical approach to representing ontologies involves defining them as a dictionary comprising specific representatives of categories of concepts within the subject area. This dictionary captures the relationships between these concepts and any restrictions imposed on them.

The conceptual basis of the ontological base, which enables semantic independence of information solutions from the features of their system implementation, comprises the following types of objects:

- terms, facts, and their role in displaying the concepts of the subject area;
- rules, conditions, and restrictions that define the relationship of entities;
- functions methods of identifying and presenting the entities of the subject area.

The final category of objects, which is not directly associated with the ontological base, is predominantly influenced by the characteristics of the chosen system tools, domain models, and syntactic mechanisms for describing data. Its incorporation into the enumerated types of objects is rationalized by the aspiration to preserve the functional comprehensiveness of extracting and presenting properties within the subject area and maintaining the object integrity of problem-oriented applications.

Therefore, by formalizing the subject area through the definition of classes and relationships, specifying individual instances of the selected classes and the values of their properties, and constructing a statement about classes and instances, it is possible to create an ontology of the information structure of the system.

To abstract any subject area, the primary and indivisible categories are recognized as "objects" and "relations" between objects. The initial data structure, known as the "object-property" table (OPT), serves as a method that unambiguously reflects the observed properties.

Formally, the subject area of the Object-Property (PO) as a system of relations between objects can be expressed as: PO = {So, Rs}, where So is a set of PO objects, Rs is a set of relations between objects (binary relations are considered for analysis), and So≠∅, Rs ≠ ∅. It is assumed that objects with similar content form distinct classes: $S_0 = \bigcup_{i \in iX} S_i$ ; $S_i \cap S_j = \varnothing$, i ≠ j, i,j∈iX is a non-empty set of indices. Interobject relations occur when objects have permanent (possibly immanent) properties. The set of all such distinct properties in the domain is $\mathrm{Pr}_j = \{pr_j\}_{j \in jX}$, where jX is a nonempty set of indices. The logical result of this perspective is the conclusion that the source material for the abstract representation of the subject area is the Object-Property Table (OPT).

Traditionally, the rows of the table correspond to the objects present in the subject area under consideration, and the columns of the Object-Property Table (OPT) represent the properties of objects (attributes, relationships, functions, and constraints).

Once the specific representatives of categories have been defined using a dictionary of concepts from the subject area, it becomes possible to construct a table that encompasses all objects and their properties for the components intended for constructing the Complex Information and Educational Environment (CIEE).

The functional diagram of the interaction of objects of the subject area, presented in Figure 6, makes it possible to evaluate the list of objects of the subject area and their connections and to compile a table of correspondence of objects and relations OPT (Table 1).

In this table, the term "none" indicates the absence of a dependence (relationship) between the specified object and all other objects in the subject area. The ontological context establishes the ontological connection of components. The symbol "+" signifies a subset of specific attribute-type properties for this object from the overall set of attributes.

A connection implies a direct relationship between the elements of the specifications. An attribute relationship exists between an object and its attributes, a link relationship connects two types of objects using a link attribute, and a type/subtype relationship links a subtype to a supertype. For instance, an attribute relationship indicates the presence of a specific attribute in the properties of the object in question, but it does not control the uniqueness of its value among other identical data for that particular object. On the other hand, a reference relationship is a connection between objects that establishes a unique value for the relationship between them. The concepts of an attribute relationship and a reference relationship can be defined as follows:

Definition 3: A → B has an attribute relationship if one of the following cases occurs: A simple attribute of type A.

Example: "Faculty" → "Name"; type A contains a link attribute b indicating type B, for example: "Module" → "Discipline."

Definition 4: A ↦ B is a reference relationship if A and B are objects of different types.

Example: "Academic performance" = "Student" ↦ "Discipline" ↦ "Module" ↦ ↦ "Assessment."

Definition 5: The link is one-sided, i.e., A ↦ does do not allow B ↦ A links, and the hierarchy "top-down" is always preserved.

The structure of objects and relationships, as depicted in the diagram, enables the description of dependencies between objects using the terms established earlier.

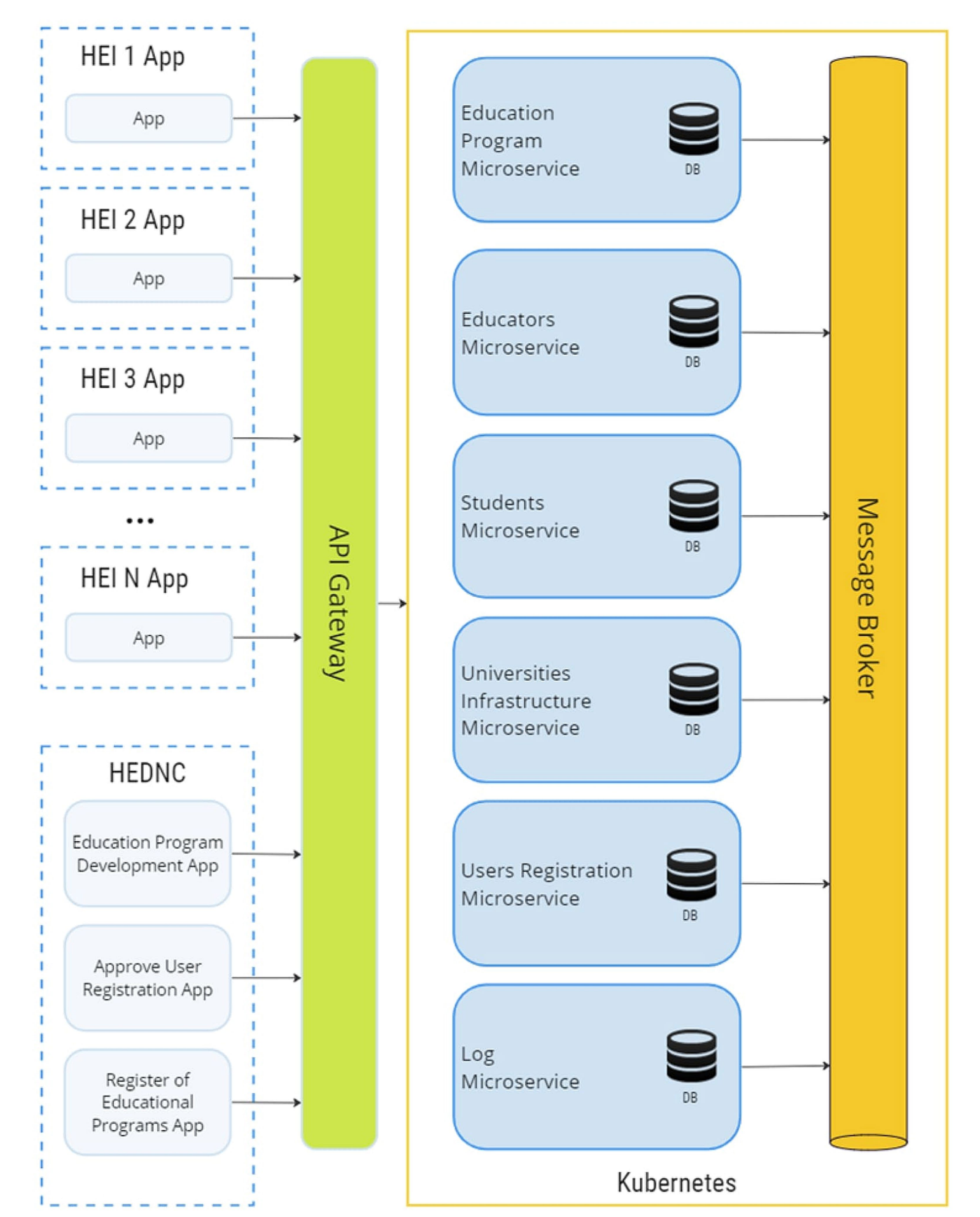


FIGURE 6
Functional diagram of the interaction of objects of the subject area.

Directories serve as general-purpose objects essential for assigning attributes to domain objects and properties of various types. In general, any object of the subject area has a set of attributes necessary for the work so we can say that:

$So_{i \in iSo} \to \left\{ pr_j, \left( pr_j \to J_{m \in mJ} \right) \right\}_{j \in jP}$, where $pr_j \to J_{m \in mJ}$ - attribute of the directory type.

The reference relationships of first-level objects are defined as follows:

TABLE 1 Correspondence table of objects and relations TOC.

| Properties, relationships/ objects | Level | Object's index | Connection of the i-th object of the 1st order | Connection of the i-th object of the 2nd order | Properties of the i-th object $\mathrm{Pr}_j$ |
|---|---|---|---|---|---|
| References | 1 | J = {1,2,…n} | None | None | + |
| Faculties | 1 | F = {1,2,…k} | None | None | + |
| Directions | 1 | D = {1,2,…m} | F[i] | None | + |
| Departments | 1 | C = {1,2,…l} | F[i] | None | + |
| Specialties | 1 | S = {1,2,…t} | F[i] | D[i] | + |
| Access | 1 | A = {1,2,…d} | None | None | + |
| Staff | 1 | K = {1,2,…h} | F[i] | None | + |
| References | 2 | Jf = {1,2,…n} | J[1] | None | + |
| Faculties | 2 | F[i] | None | None | + |
| Departments | 2 | C = {1,2,…c} | F[i] | None | + |
| Directions | 2 | D = {1,2,…k} | F[i] | None | + |
| Specialties | 2 | S = {1,2,…t} | F[i] | D[i] | + |
| Staff | 2 | K = {1,2,…h} | F[i] | C[i] | + |
| Groups | 2 | G = {1,2,…t} | S[i] | None | + |
| Disciplines | 2 | L = {1,2,…p} | S[i] | None | + |
| Teachers | 2 | T = {1,2,…q} | K[i] + L[i] | G[i] | + |
| Tutors | 2 | P = {1,2,…v} | K[i] | G[i] | + |
| Students | 2 | U = {1,2,…x} | G[i] | None | + |
| Access | 2 | A = {1,2,…d} | F[i] | None | + |
| Modules | 2 | M = {1,2,…m} | L[i] | None | + |
| Academic performance | 2 | R = {1,2,…r} | U[i] | M[i] | + |
| Tests | 2 | H = {1,2,…z} | M[i] | None | + |
| Test results | 2 | B = {1,2,…b} | U[i] | H[i] | + |

- «Directions»: $D_{j \in jD} \mapsto F_{i \in iF}$;
- «Departments»: $C_{j \in jC} \mapsto F_{i \in iF}$;
- «Specialties»: $S_{j \in jS} \mapsto F_{i \in iF} \to D_{j \in jD}$;
- «Frames»: $K_{j \in jK} \mapsto F_{i \in iF}$;
- «Access»: $A_{j \in jA} \mapsto F_{i \in iF}$.

At the second level, many objects, which are also represented at the first level, exhibit a reference relationship—a connection to a specific type of object, "Faculty." If we denote the i-th faculty from the set of objects of this type as $F_{i \in iF} = F_i$, then for all objects within this faculty, the relationships will appear as follows:

- «Directions»: $D_{j \in jD} \mapsto F_i$;
- «Departments»: $C_{j \in jC} \mapsto F_i$;
- «Access»: $A_{j \in jA} \mapsto F_i$;
- «Specialties»: $S_{j \in jS} \mapsto F_i \mapsto D_{j \in jD}$;
- «Disciplines»: $L_{j \in jG} \mapsto S_{j \in jS}$;
- «Frames»: $K_{j \in jS} \mapsto F_i \to C_{j \in jC}$;
- «Groups»: $G_{j \in jG} \mapsto S_{j \in jS}$;
- «Teachers»: $T_{j \in jT} \mapsto K_{j \in K} \mapsto L_{j \in jL} \mapsto G_{j \in G}$;
- «Supervisor»: $P_{j \in jP} \mapsto K_{j \in K} \mapsto G_{j \in G}$;
- «Students»: $U_{j \in jU} \mapsto G_{j \in G}$;
- «Modules»: $M_{j \in jM} \mapsto L_{j \in jL}$;
- «Academic Performance»: $R_{j \in jR} \mapsto U_{j \in U} \mapsto M_{j \in jM}$;
- «Tests»: $H_{j \in jH} \mapsto M_{j \in jM}$;
- «Test results»: $B_{j \in jB} \mapsto U_{j \in U} \mapsto H_{j \in jH}$.

Structural relationships become apparent when there are reference-type properties in the objects of the subject area. The values of such properties are references to existing objects.

The modifications introduced to the conventional understanding of the data formation stage regarding the subject area enable the identification of classes of objects reflecting their heterogeneity. This is achieved through simple transformations of the obtained OPT and by examining the composition of properties and their ability to enter structural relationships.

Let us consider replacing the value "none" with "0" in the OPT, and all other values with "1." This transformation would turn the source table into an incident matrix for "object-properties." The information within this matrix is adequate for constructing a conceptual model of the subject area. The algorithm proposed for this process primarily involves adding and removing specific rows and columns in the matrix to achieve the following goals:

- Identifying object classes by retaining one instance of each set of matching strings.
- Eliminating invalid attributes from the model by removing "zero" columns.

- Specifying the class of unidentified objects of the attribute type (adding a new column accordingly).
- Specifying the existence of a particular class of unknown objects (adding a new specially constructed row).

This results in an incidence matrix of dimensions $m \times n$, where $1 \leq m \leq r + a$, $1 \leq n \leq s + k$, defining the correspondence $I \subseteq Cl \times A$. Here, Cl represents the set of identified classes of objects (primary concepts in the domain specifications), A is the set of features corresponding to components (attributes), and it's evident that $Cl \neq \varnothing$, $A \neq \varnothing$, $I \neq \varnothing$. Therefore, classification is manifested in the presence and composition of Cl, and the semantics of subset A reflects associations of objects in the subject area.

The forms of abstraction discussed serve as the foundation for the relational approach in practical database modeling. The ontological approach enhances the abstraction of generalization, where such classes are linked to a higher-level parent object. In this scenario, the domain ontology is depicted as a model that describes the structure of classes, encompassing both natural classes defined in the domain model and abstract classes derived from generalizing specifications of actual classes.

Considering the flexibility in selecting domain properties, it is evident that multiple domain ontologies can depict the same actual classes of objects in different manners. Consequently, these ontologies vary in generalizable concepts and the inclusion of relationships. Ontological analysis leads to the formulation of a conceptual model that delineates the structure of database classes.

The efficiency of ontological analysis lies in the comprehensive integration of available data on the subject area and the formal, algorithmic transformation of the conceptual object-feature model into the ontology of the subject area.

Using the ontological model proposed in the paper, the architecture of the universities' CIEE database has been developed, and classes and their properties for implementing this model have been determined. Additionally, a structural model of the microservices system has been developed.

## 3.5 Structural model of microservices of the integrated information and educational system "quality management of higher and postgraduate education"

Contemporary methods for developing extensive software systems often employ an object-oriented approach, which primarily involves representing a software system as a collection of independent entities (objects) that interact with each other. Each entity is responsible for maintaining the information essential for its functioning and, in addition, defines its own behavior. The fundamental concept of an object-oriented approach lies in the capability to break down a system into numerous distinct entities, each of which can be instantiated into any number of instances (objects) with their unique attributes. The connections between objects articulate the system's structure.

The tools must meet the following basic requirements:

- The tools should be universal and flexible, based on a metadata database (metabase) for parametric adjustments to meet the specific requirements of users. This is crucial for iterative adaptation of the educational process to align with the principles of the Bologna Declaration, incorporating algorithms and parameters for calculating ratings, weight coefficients, etc.
- The system should support the maintenance and general use of a reference database for universities. This includes information on the structure, email addresses, network identifiers, websites, additional links to teaching materials within the institution, and on the internet. Navigation through the database should be intuitive for end-users.
- The tools should support the maintenance of operational databases concerning the results of various forms of student knowledge assessments by faculties and specialties.
- The system should take into account significant differences in the technical characteristics of individual computers within higher education institutions.
- Ensuring the reliability and security of data storage is crucial. The system should implement strict regulation of data access rights for different user groups, and user identification through software-based electronic signature mechanisms.
- The system should support electronic document management based on XML documents. This ensures adaptability to new software and hardware platforms and accommodates the heterogeneity of technical and software tools within the computer network.
- The system should support the creation of documents compatible with Microsoft Office (including cloud solutions) on electronic media. Additionally, it should allow for the relatively simple expansion of document sets by creating and registering new document templates in the database.
- The tools should provide integration with schedule planning programs and integrate seamlessly with existing software tools for distance education and computer testing.

The outlined requirements, based on the functional purpose, have led to the conceptual model of the university. They have also significantly influenced the functional and technical characteristics of the system and guided its software implementation, including the development of object-oriented and structural models and algorithms through conceptual, logical, and physical modeling processes.

To implement the information system "quality Management of Higher and Postgraduate Education," a conceptual model of the system architecture and the logical structure of relational database tables were developed (Figure 7).

### 3.5.1 Access control

The system's private data should not be publicly available. They must be delimited following the access rights defined by the administrator. The description of access rights is given in this Technical Specification in the section "Functional requirements."

Users of the NCRVO IC can be divided into the following roles with access to the corresponding functionality:

1. Information system Administrator;
2. Local Administrator;
3. Information system developer;
4. NCRVO employee confirming or rejecting the user registration application;
5. Developer of the educational program;
6. University Administrator;

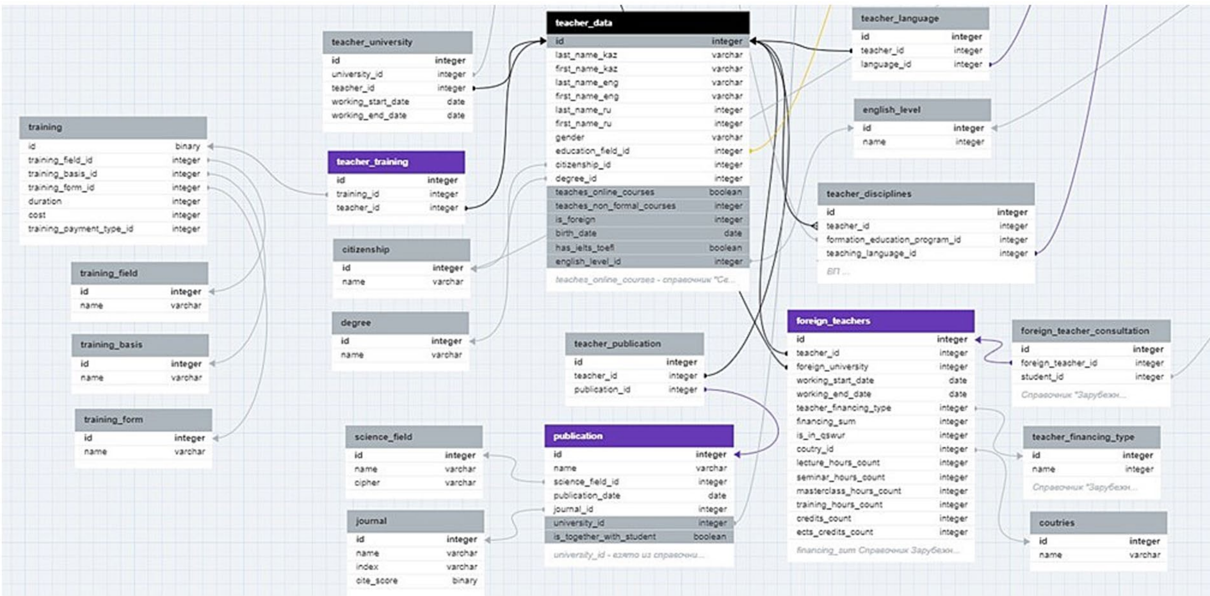


FIGURE 7
Conceptual model of the architecture of the system "quality management of higher and postgraduate education".

7. Representative of the coordinating organization;
8. Registry Operator OP;
9. Expert OP;

### 3.5.2 Information security and protection

The system must be protected from unauthorized access to information from the outside, destruction of information in emergencies, and unauthorized use and distortion of data during transmission over communication channels.

The system should provide:

- Personalized user login to the system (with the provision of centralized rights settings for user groups, access rights to system components, and the ability to perform certain operations);
- Logging of user actions in the system.

### 3.5.3 Functionality

The system needs to implement Registry generation services 1, 2, 3. To do this, it is necessary to create microservices that form the following registries according to the approved rules or described business processes:

- Register of Accreditation Agencies (Register 1)—a list of national and foreign accreditation bodies included in the registers and (or) associations of accreditation bodies of Member States, the Organization for Economic Cooperation and Development;
- Register of Accredited Educational Organizations (Register 2)—list of accredited educational organizations;
- Register of Accredited educational programs (Register 3)—list of accredited educational programs (specialty) universities.

It is also necessary to implement microservices in the information system to collect data from organizations of higher and postgraduate education according to the "national model of QA and a successful university"—this is high-quality content (Education Program), high-quality staff (Educators), high-quality contingent (Students) and high-quality infrastructure (Universities), as well as microservices providing access and control of roles users in the system and maintaining user notifications.

### 3.5.4 Microservice «educators»

The microservice "Educators" contains data on teachers at universities. The central table in this microservice is the "teacher_data" table, which contains the primary data of teachers, such as name, gender, and citizenship. It also stores data on the essential academic characteristics of the teacher, for example, his academic degree, teaching distance and informal courses, and others. In addition to the central table, there are four subgroups of tables containing information on one specific topic (Figure 8):

- Tables that supplement the basic information on teachers in the "teacher_data" table. These are directories referenced by identifiers from "teacher_data." For example, if the citizenship identifier is stored in "teacher_data," it refers to the "citizenship" table, which stores a list of countries of which teachers are citizens. This group of tables, together with the central table "teacher_data" is necessary to obtain the essential characteristics of teachers.
- A group of tables for foreign teachers. These tables describe the data of teachers attracted to Kazakhstan from foreign universities. The table "foreign_teachers" is displayed separately from the main table of teachers since data is collected for foreign teachers that differ from Kazakh teachers. To fully assess the contribution of scientists attracted from abroad, data such as the number of seminars, lectures, and master classes held, as well as advising Kazakhstani students in writing scientific articles and dissertations, are collected for them.

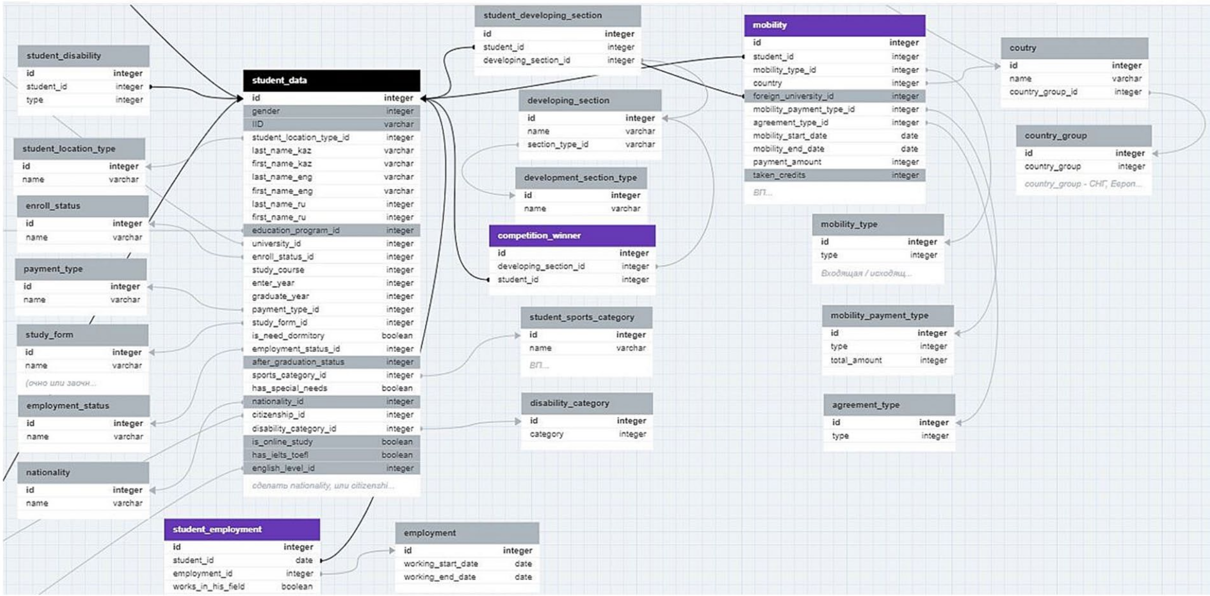


FIGURE 8
Microservice «Educators» ERD. Microservice «Students» ERD.

- Tables on scientific publications of teachers. The presence of scientific publications in prestigious journals among teachers is an essential indicator of the quality of education at a particular university. This group of tables provides information on which university professors are involved in scientific activities, in which journals they are published, and also whether they publish works together with students, thereby contributing to the academic development of universities and a new generation of scientists.
- A group of tables on teacher training courses. This group of tables will allow you to assess the relevance of teachers' knowledge for teaching subjects. The analysis will be based on such parameters as the field of education qualifications, the form of courses, based on which the courses were held, the number of hours, and others.

### 3.5.5 Microservice «students»

The microservice of students stores data about students in different sections. The main table of the microservice, student_data, stores basic information on students (name, gender, date of birth) and primary academic data, such as the university where the student studies, his educational program, and others. This microservice contains all the necessary information for monitoring the contingent of students in all higher educational institutions, analyzing the quality of educational services and the conditions provided. The microservice will also allow analyzing student performance and its correlation with various student parameters. This will be done using performance indicators such as GPA and IGPA. While GPA is already a well-known assessment method most higher education institutions use worldwide, IGPA (integral GPA) is a new and less popular indicator. However, it should be noted that the integral GPA considers academic performance and the student's achievements in research and socio-social activities. The microservice data will comprehensively analyze the student's academic performance and the quality of services provided.

In the microservice of students, four tables can be distinguished that describe specific student data. The central "student_data" and its auxiliary directories have groups of tables containing the following data:

- Athletic achievements of students. The data includes sports and developmental sections in which the student participates, his sports category, competitions, and awards. This is an integral part of overall student health and activity monitoring. In addition, storing data on sports achievements allows you to see how a student balances between study and sports. This can help in adapting the workload and planning classes. In general, including sports achievements in the microservice of students can create a more complete picture of student life and promote a healthy lifestyle.
- Academic mobility. This group of tables contains information on external incoming and outgoing mobility. It stores data on which foreign university mobility is carried out, funding sources, and types of mobility agreements. The collected data on academic mobility can be used to analyze trends in student mobility, identify popular exchange programs, and create mobility reports for internal and external audiences. This will make it possible to improve educational programs, develop new courses, and cooperate with other educational institutions to create more attractive exchange programs.
- Employment of students. Storing student employment data can help track graduates' career success and adapt educational programs to the needs of the labor market. Also, according to the results of graduates' employment, it is possible to judge how successfully the training program prepares students for real life and what positions they get into.

### 3.5.6 Microservice "education programs"

The microservice of educational programs contains information about various training courses, programs, and academic disciplines offered in educational institutions. The main table in the microservice,

 10.3389/feduc.2024.1291831

"education_program," contains the main characteristics of the educational program. Among them are the field of education, the language of instruction, whether the program is distance or informal, whether it is carried out within the framework of any state program, and others. The microservice also stores data on educational programs (Figure 9):

- Accreditation of educational programs. The storage of accreditation data allows you to track the compliance of educational institutions with international standards and provide evidence of the legitimacy and quality of education. Also, these data will help to assess the attractiveness of universities for cooperation since many organizations, educational institutions, and employers can provide their services and cooperation only with accredited programs.
- Formation of educational programs. This group of tables provides information on the content of the educational program: disciplines, number of credits, model, etc. The analysis of the content of the educational program will help educational institutions maintain a high quality of education, meet the requirements of the labor market, adapt to new trends, and ensure the successful training of students. Evaluate how effective the teaching of each discipline is, which teaching methods are the most successful, and which require improvement. It will also allow the educational institution to predict the need for educational materials, literature, teachers, and other resources.
- Joint educational programs. Joint programs often provide students with unique educational opportunities, such as access to experts from different educational institutions, international experience, and expanded networks of contacts. These features can be highlighted in the program data. Storing this data in educational programs' microservices helps manage and take advantage of all aspects of these specific educational partnerships more effectively.

### 3.5.7 Microservice « university »

The microservice of universities provides a centralized and convenient way to manage information about educational institutions, which provides better access to data for all interested parties. The primary information about universities is stored in the "university" table, referenced by other groups of tables containing different types of information about the university (Figure 10). Among them:

Availability of sports facilities, laboratories, dormitories, and buildings at the university. An analysis of the equipment of universities with such facilities will help to assess the comfort of the conditions created for students. This, in turn, will give an idea of how much and in which educational institutions funds should be invested. Monitoring the availability of dormitories for students is especially important since the housing issue affects the choice of university and sometimes even is an obstacle for nonresident students.

- Digital resources. The analysis of digital resources at the university is of great importance for the modern educational process and the learning environment. The technological age dictates new standards for higher education, and Kazakh educational institutions must follow them to keep up with the times. Storing data on digital equipment will give an understanding of the competitiveness of universities and the availability and flexibility of educational programs.
- Financing of universities. This information will help to track the effectiveness of the disbursement of allocated funds. Using various indicators of the university will help determine whether these funds are being spent for their intended purpose and whether there is a result from financing.
- Accreditation. Information about university accreditation is essential when choosing an educational institution, as it affects the quality of education, the legitimacy of diplomas, career opportunities, and many other aspects of students' educational experience. The analysis of this data is essential because accreditations help universities improve their programs and

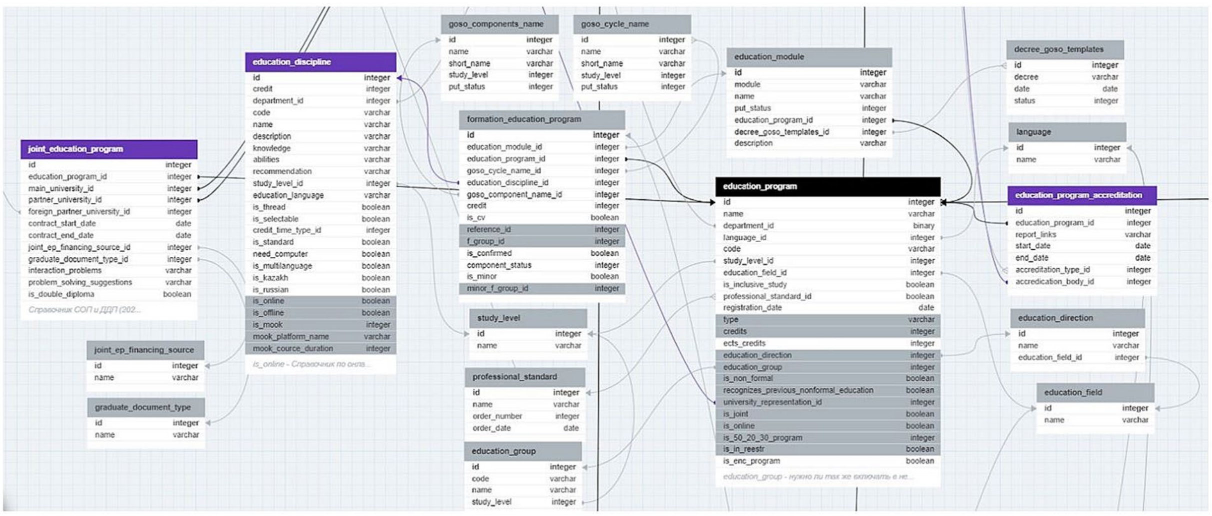


FIGURE 9
Microservice « Education programs » ERD.

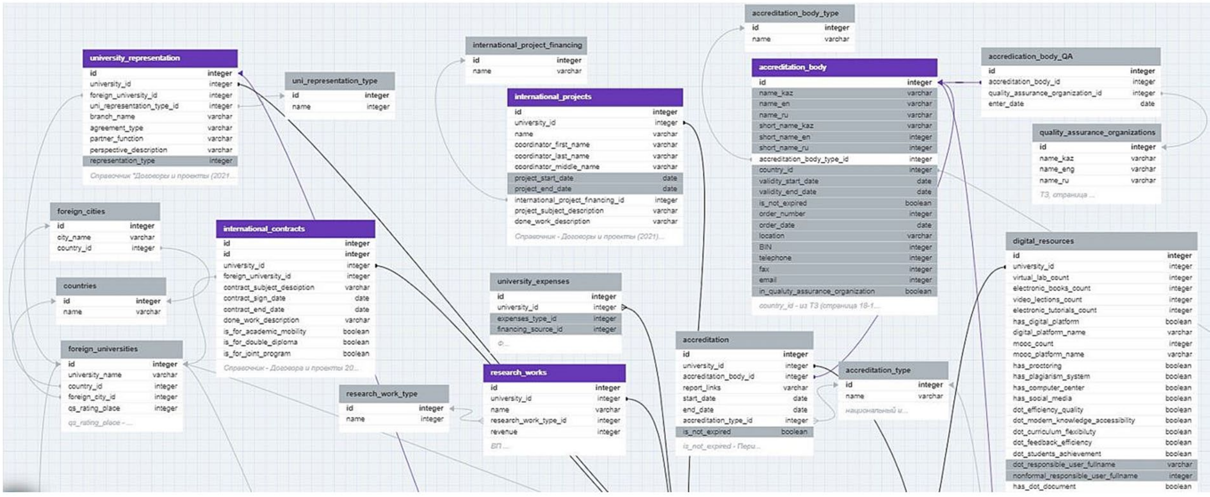


FIGURE 10
Microservice « University» ERD.

ensure their relevance continuously. This will give an idea of the recognition of universities at the international level.

- International activities. Storing data on international activities in the microservice of universities allows you to manage international initiatives, support students in an international environment, attract international students, and develop international cooperation to improve the quality of education and research.

## 4 Discussion

The developed information system "quality management of higher and postgraduate education" is undergoing pilot implementation at Astana IT University from the beginning of 2023. To this end, in January–February 2024, university employees of the relevant departments were trained on the system's features. At the same time, data on students, university teachers, information on educational programs, curricula, disciplines, etc., began to be entered. The schedule for collecting and entering these data was performed according to the algorithm described in section 3.1. To build the interaction environment of the agents at Astana IT University, the constructed structural model of the complex information-educational environment of the university and the interaction scheme of the objects of the information-educational environment of the educational process management system were used (section 3.2.). Based on these schemes, as well as the concept of microservices (Chapter 3.3.), the information system "Quality Management of Higher and Post-University Education" was developed.

In total, during the period, information was entered on more than 500 teachers and more than 5,000 students in the "Computer Science" field, 10 educational programs at the "Bachelor's" educational level, seven educational programs at the "Master's" level, and two educational programs at the "Doctor of Philosophy" level. For these programs, information on 430 disciplines and links to educational and methodological complexes for these disciplines have been entered.

The pilot implementation of the system is still ongoing, but preliminary conclusions can already be drawn regarding the results of its work. First of all, the system greatly simplified the possibility of generating reports and analytics related to the educational process. For example, the formation of analytics on the learning results of a particular student or group of students can take place in real-time. This made it possible to improve the quality management of the educational process. In addition to monitoring the results of students' studies, the system provides feedback between students and teachers of disciplines, making it possible to evaluate teachers' work and point out shortcomings. It also has a positive effect on the quality of teaching the necessary material. The pilot implementation of the system will be carried out until the end of 2023/2024 study year, after which the results will be summarized at the level of Astana IT University with the calculation of efficiency. From 2024, it is planned to implement the system in other universities of the Republic of Kazakhstan.

When the pilot implementation of the information system "quality management of higher and postgraduate education" shows its effectiveness, this information system will be adapted for all universities of the Republic of Kazakhstan.

The methodological principles outlined in this study are the basis for the practical implementation of modern information technologies. This will improve some management of higher education.

## 5 Conclusion

The development of a comprehensive information and educational system "quality management of higher and postgraduate education" makes it possible to make higher education in the country more competitive, ensure its quality and compliance with international standards, as well as promote the participation of Kazakhstani institutions of higher education in international educational programs and initiatives. This helps students and teachers expand their knowledge and experience and promotes the exchange of knowledge and cultural values between countries.

The developed information model was based on the model of a complex information and educational environment of a higher educational institution and the Ontological model of the database of the integrated information and educational environment. These theoretical models have made significant progress in the development of the architecture of information compression and its microservices.

The developed system underwent preliminary pilot implementation at Astana IT University (Republic of Kazakhstan). Implementation will continue until the end of 2023/2024 study year. However, preliminary conclusions can already be drawn regarding its results. The use of the system made it possible to improve the quality management of the educational process, provide productive feedback between teachers and students, and monitor the educational process and student success in real-time.

Further research is needed on the effectiveness of the implementation of the "quality Management of Higher and Postgraduate Education" system in various Higher Education Institutions. In particular, the research needs the influence of the scale of the university on the effectiveness of education quality management. Also, we can assume the existence of an unexpected influence of the distributed structure of some universities.

The application of the proposed model of support and improvement of higher education requires coordination with the legislation of each country in the field of education and science.

The proposed technical solution was developed taking into account the educational needs of the Republic of Kazakhstan. For some countries, such as Ukraine, the model needs minimal changes. At the same time, it may require significant changes when implemented in countries that are not participants in the Bologna process.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

AB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SO: Funding acquisition, Resources, Supervision, Writing – review & editing. AM: Data curation, Writing – review & editing. OK: Conceptualization, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing. MH: Formal analysis, Validation, Writing – review & editing. YA: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. NM: Funding acquisition, Project administration, Writing – review & editing, Software. AF: Data curation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing.

## Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research has been funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR18574103 with the topic: "To increase the competitiveness of universities in Kazakhstan through the reengineering of the national system of quality assurance of higher education").

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## References

Alzahrani, B., Bahaitham, H., Andejany, M., and Elshennawy, A. (2021). How ready is higher education for quality 4.0 transformation according to the LNS research framework? *Sustain. For.* 13:5169. doi: 10.3390/su13095169

Antony, J. (2014). Readiness factors for the lean six sigma journey in the higher education sector. *Int. J. Product. Perform. Manag.* 63, 257–264. doi: 10.1108/IJPPM-04-2013-0077

Biloshchytskyi, A., Kuchansky, A., Andrashko, Y., Omirbayev, S., Mukhatayev, A., Faizullin, A., et al. (2021). Development of the set models and a method to form information spaces of scientific activity subjects for the steady development of higher education establishments. *Eastern Eur. J. Enterp. Technol.* 3, 6–14. doi: 10.15587/1729-4061.2021.233655

Biloshchytskyi, A., Kuchansky, A., Paliy, S., Biloshchytska, S., Bronin, S., Andrashko, Y., et al. (2018). Development of technical component of the methodology for projectvector management of educational environments. *Eastern Eur. J. Enterp. Technol.* 2, 4–13. doi: 10.15587/1729-4061.2018.126301

Cabero-Almenara, J., Guillén-Gámez, F. D., Ruiz-Palmero, J., and Palacios-Rodríguez, A. (2021). Digital competence of higher education professor according to DigCompEdu. Statistical research methods with ANOVA between fields of knowledge in different age ranges. *Educ. Inf. Technol.* 26, 4691–4708. doi: 10.1007/s10639-021-10476-5

Cardoso, S., Rosa, M. J., and Stensaker, B. (2016). Why is quality in higher education not achieved? The view of academics. *Assess. Eval. High. Educ.* 41, 950–965. doi: 10.1080/02602938.2015.1052775

Haleem, A., Javaid, M., Qadri, M. A., and Suman, R. (2022). Understanding the role of digital technologies in education: a review. *Sustain. Operat. Comput.* 3, 275–285. doi: 10.1016/j.susoc.2022.05.004

Hill, F. M., and Taylor, W. A. (1991). Total quality management in higher education. *Int. J. Educ. Manag.* 5, 4–10. doi: 10.1108/09513549110144724

Kostopoulos, G., and Kotsiantis, S. (2022). Exploiting semi-supervised learning in the education field: a critical survey. *Adv. Mach. Learn.* 2, 79–94. doi: 10.1007/978-3-030-76794-5_5

Kuchansky, A., Biloshchytskyi, A., Andrashko, Y., and Wang, Y. (2022). Devising a competence method to build information spaces for executors of educational projects in a dynamic environment. *Eastern Eur. J. Enterp. Technol.* 1, 66–73. doi: 10.15587/1729-4061.2022.253043

Lewis, C. C., Fretwell, C. E., Ryan, J., and Parham, J. B. (2013). Faculty use of established and emerging technologies in higher education: a unified theory of acceptance and use of technology perspective. *Int. J. High Educ.* 2, 22–34. doi: 10.5430/ijhe.v2n2p22

Nasim, K., Sikander, A., and Tian, X. (2020). Twenty years of research on total quality management in higher education: a systematic literature review. *High. Educ. Q.* 74:75-97. doi: 10.1111/hequ.12227

Nuere, S., and De Miguel, L. (2021). The digital/technological connection with COVID-19: an unprecedented challenge in university teaching. *Technol. Knowl. Learn.* 26, 931–943. doi: 10.1007/s10758-020-09454-6

Pinho, C., Franco, M., and Mendes, L. (2021). Application of innovation diffusion theory to the E-learning process: higher education context. *Educ. Inf. Technol.* 26, 421–440. doi: 10.1007/s10639-020-10269-2

Prim, R. C. (1957). Shortest connection networks and some generalizations. *Bell Syst. Tech. J.* 36, 1389–1401. doi: 10.1002/j.1538-7305.1957.tb01515.x

Raharjo, H., Xie, M., Goh, T. N., and Brombacher, A. C. (2007). A methodology to improve higher education quality using the quality function deployment and analytic hierarchy process. *Total Qual. Manag.* 18, 1097–1115. doi: 10.1080/14783360701595078

Seale, J., Georgeson, J., Mamas, C., and Swain, J. (2015). Not the right kind of 'digital capital'? An examination of the complex relationship between disabled students, their technologies and higher education institutions. *Comput. Educ.* 82, 118–128. doi: 10.1016/j.compedu.2014.11.007

Shohel, M. M. C., Ashrafuzzaman, M., Islam, M. T., Shams, S., and Mahmud, A. (2021). "Blended teaching and learning in higher education: challenges and opportunities" in *Handbook of research on developing a post-pandemic paradigm for virtual technologies in higher education*, 27–50. doi: 10.4018/978-1-7998-6963-4.ch002

Tohara, A. J. T., Shuhidan, S. M., Bahry, F. D. S., and bin Nordin, M. N. (2021, 2021). Exploring digital literacy strategies for students with special educational needs in the digital age. *Turk. J. Comput. Math. Educ.* 12, 3345–3358. doi: 10.17762/turcomat.v12i9.5741

Zunimova, G., Soltan, G., Likhacheuski, D., and Issayeva, N. (2023). Information-logical model of education optimization in remote mode. *Sci. J. Astana IT Univ.* 14, 57–70. doi: 10.37943/14ZEXL9869