Intelligent Semantic Educational System: Purpose and Structure

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***Abstract*—In the article, the purpose and the structure of national intelligent educational system is considered. The properties and some requirements to the system along with the structural layers content are proposed. The system is plotted as interoperable, adaptive, multi-agent, each of the agents having its' own personal assistant as an intelligent subsystem to provide self-monitoring, control and establishing connections and communications within the system and with the third parties. The obtained results will allow determining the direction for development of intelligent educational system of national level as well as the subsystems and their educational content by means of the artificial intelligence technologies.**

***Keywords*—intelligent educational system, semantic system intelligence, interoperability, multi-agent system, personal assistant**

I. Introduction

In the last decade, especially after the Covid-19 pandemic, the development and implementation of information systems has been a top priority for almost all countries in the world. Today, information systems designed for use on a global scale have become a relevant area of research and development – not only by individual enterprises, but by corporations, sectors of the economy, and at the state level. In our country, this issue is also given much attention.

In any state, the level of development of society, public relations and, to a large extent, the economy is determined by the level of education and health of the members of this society. The quality of education significantly affects the intellectual potential of society as a whole, not only its younger generation, but also the future of the country.

Recently, a large number of scientific studies and publications have appeared in the field of development of integrated information environments. The issue of creating integrated educational environments using artificial intelligence technologies, network technologies, automation of administrative activities of educational institutions of different levels is being actively studied [1], [2]. Research in this direction is also being conducted in our country. Thus, the structure of the Republican information and educational environment is proposed [3]–[5]. The solutions proposed in these works allow creating a platform at the level of the education sector and include integration with various republican platforms and services, as well as with information systems at the level of higher education institutions, schools, and kindergartens. This is relevant work, and not only for the education system, but is of particular importance for it.

II. The structure of the intelligent educational system

Some problems to be covered within the intelligent semantic educational system (ISES). In addition to solving the problem of digitalization and informatization of education, the development and implementation of such information and educational environments should be aimed at solving important problems that exist today in the field of education at all its levels in our country. Among them are the creation of interactive semantic textbooks in various disciplines, automation of work processes in the work of teachers and administrators; personalization of education, aimed at the school level at identifying the interests of students, their inclinations to a particular type of activity, in general, at the career guidance of the student, at the level of professional training - at improving the quality of knowledge and skills of the student, taking into account his abilities and interests in the chosen field; increasing the degree of interaction between theory and practice in professional education; providing opportunities to improve the level of education of each participant in the system; unification of the processes of interaction of participants in the educational process; professional expertise of the quality of educational resources, pedagogical methods and techniques.

The requirements to the ISES. An educational semantic intelligent system must meet such requirements as adaptability, interoperability, security, scalability, communication, the ability to analyze processes both within the system and when interacting with third-party systems, and the use of a single platform for the development and operation of subsystems. Adaptability – the ability of a system to change when external conditions change so that the goal of the system's functioning is achieved, even if changes in external conditions prevent this – is an important property for maintaining the system's operability when not only external conditions change, but also when its structural elements and/or connections within the system between its elements need to change. When new structures emerge in the education system, or the functions of existing elements change, it is important to maintain the system's operability during the transition period. Interoperability is not only a requirement for the functional compatibility of the technical components of the system, but also a necessity for the semantic compatibility of its subsystems. Security concerns the personal data of system users and all participants in the educational process, the data of the system itself, the processes of interaction within the system and with external systems, etc. Scalability is responsible for the ability to expand the system, i.e. add both new hardware and software resources to it, as well as increase the number of users and the diversity of their roles in the system. Communicability acts as a requirement for processing various types of data (information), using different approaches in the process of preparing and transmitting data necessary for intra-system communication, including users (students, teachers, etc.), along with interoperability is responsible for the semantic compatibility of the system and its individual subsystems and user requests. The ability to analyze processes - reflection - a requirement to analyze one's state at any given moment and make decisions on the need to correct actions to maintain the working state. Using a single platform for developing and operating the system will allow unifying and simplifying all technological and organizational processes, reducing the labor intensity of new developments and their implementation, complying with the above requirements, and training new developers, administrators, and users of the system faster and easier. The list of requirements can be changed in the course of research and work on creating and filling the system.

The structure of the ISES. Educational activities of any structures and organizations in our country are regulated centrally, therefore, automation of educational activities should be carried out based on the hierarchy of the entire education system both in terms of the educational process itself and the management of educational activities. Thus, the first step towards solving the problem of educational activities automation on a global scale can be the development of the architecture of an intelligent interoperable information system of education and the provision of educational services, taking into account the requirements for the system.

The educational semantic intelligent system should be considered as a global community of local intelligent systems of individual educational organizations and associations, down to the smallest unit of this community - an individual user. This global community will include educational institutions of different levels - schools, secondary specialized educational institutions,

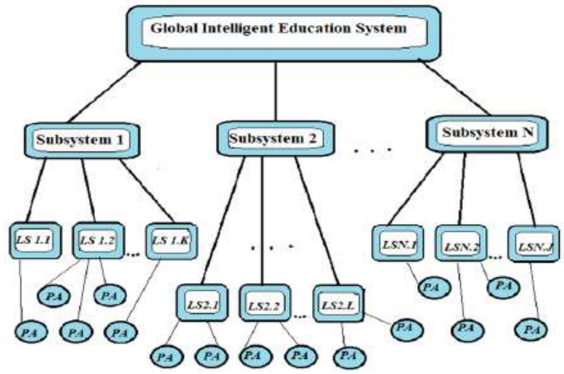

Figure 1. General structure of the global intellectual educational system

higher educational institutions, etc. - research institutes in the field of education, institutions for advanced training of specialists of different levels, enterprises and organizations that train their employees, organizational and management structures, and finally, individual users, such as schoolchildren, students, postgraduates, and adult participants in the educational process. All of them are included in the general global system as separate subsystems, also organized according to the principle of hierarchy. Separate subsystems can organize families among themselves, which also represent an intelligent system, depending on the direction of activity, the level of education of the student, the professional focus of training, etc. The diagram of the system is presented in Figure. 1. This structure is obviously a multi-agent one, so all the technologies, requirements and properties of the multi-agent systems are expected here.

The main role in organizing the work of such a global structure is assigned to the intelligent system "Personal Assistant" (PA). At the same time, the user of such a system is understood to be a unit of the system – an individual (as a participant in the educational, administrative or other process within the global system) or one of its subsystems in the global community, including the global system itself.

Main participants of the ISES:

- Learners
- Teachers (subject teachers, organizers, speech therapists, psychologists, psychologist-correctors, class teacher (curator), personal mentors (tutors))
- Experts in the field of educational content, pedagogical methods, teaching methods, etc.
- Administrators (educational institutions, technical, network, learning platform, etc.)
- Developers (technical – programmers, testers, developer specialists in various fields of knowledge, teachers, psychologists, lawyers, etc.)
- Observers with the right to control processes (representatives of government agencies associated with educational standards, for example, the Ministry

of Education, National Institute for Higher Education, etc., parent/legal representative of a (underage) learner)

Each participant in the system can have different roles. For example, a teacher can act as an expert or administrator, a developer – as an observer or expert, any participant as a learner, etc. These roles determine the availability of data and services of the system for each participant at any given moment. Data is collected in the system and provided to the user upon request, personal data is primarily stored by the user, in his Personal Assistant (PA), and can be transferred upon request, provided that the requester has the right of access to this personal data processing. The system operation can be organized on the principle of a peer-to-peer network, each node of which can be a separate subsystem (network) performing its tasks. Individual elements of the system can be designed and developed as fractal structures, which determines the possibility of unification and standardization of the development of such systems, simplifying their implementation and operation. The internal representation of data and knowledge of all subsystems must be the same, the language of communication of subsystems and users must be defined. Individual elements of the system must be interoperable.

III. The main structural layers of the ISES

The internal architecture of each subsystem of the global system, including the global system itself, can be represented as consisting of several main layers: Data – Semantic processing – Components based on artificial intelligence – Applications and connection with existing third-party platforms. The layers "Semantic processing" and "Components based on AI" have a common element "Subsystem of explanations", which allows responding to user requests about the decisions made by the system. All these layers are united by a single infrastructure, the entire system, each of its subsystems and each participant (user) have in their structure the control element "Personal assistant (of the system)" (PA), which ensures communication and interoperability of all elements of the system (Fig. 2). Let's look at these layers in more detail.

Data Layer includes databases/knowledge bases, multi-modal data, data about trainees. *A. Databases/knowledge bases.* The data base and knowledge base make the heart of the system, acting as a structured repository of educational knowledge, administrative and managerial models, and expert knowledge. It is an integrator of educational and methodological materials, methods, and technologies for determining personal priorities and psychological characteristics of students. It combines otologies (formal knowledge models) and knowledge graphs to represent concepts, relationships, and resources specific to subject

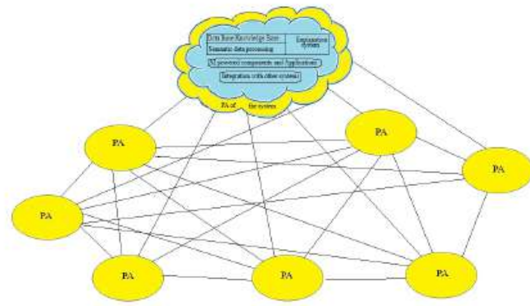

Figure 2. The structure of a separate subsystem and the scheme for organizing the interaction of personal assistants of subsystems and users of the global system

areas and methodological approaches. Each subsystem can have its own database and knowledge base, but they must be largely general, i. e. accessible to each subsystem, and respond to user requests. Otologies and knowledge graphs are part of the knowledge bases.

Otologies define the structure of educational concepts, relationships, and hierarchies. They are formal, machine-readable structures that define the vocabulary, concepts, and relationships within a subject area (e.g. mathematics, computer science, physics, or linguistics). Key features present as Classes/entities to represent real or abstract concepts (e.g., course, skill, assessment); Properties/attributes: define characteristics of entities (e.g., a course has prerequisites, duration, learning outcomes); Relationships: define how entities interact (e.g., student → enrolled → course; skill → required → prerequisite skill); Hierarchies: organize concepts into taxonomies (e.g., math → algebra → linear algebra).

Today, in world practice, there are such standards as RDF – a standard for representing data in the form of triples (subject-predicate-object) [6], – OWL, which extends RDF to provide the possibility of complex reasoning [7].

Knowledge graph: A graphical representation of interconnected entities (nodes) and relationships (edges). It extends otologies by dynamically linking real-world data (e.g. student performance, resources, and institutional policies).

Structure:

- Nodes: represent entities such as Student, Course, Video, Grade, or Instructor.
- Edges: represent relationships (e.g. Student X → enrolled → Course Y; Video Z → teaches → Concept A).
- Triple format: (Subject, Predicate, Object) (e.g. Course 1 has prerequisite - Algebra).

Functions:

- Multimodal integration: Links text, images, videos, and interactive content to concepts

- Dynamic updates: evolve as new data is added .
- Cross-domain connections: enable interdisciplinary learning.

Implementation tools available today include: Triplestores [8] for storing and querying RDF/OWL data; graph databases like Amazon Neptune [9].

B. Multi-modal data. Structured storage of educational resources (textbooks, videos, tests, simulations) and interactive content with semantic annotations. Main features:

- Metadata tagging;
- Annotation;
- Ontology links: Resources are linked to the knowledge graph.

C. Information about users-learners:

- Learner profiles (demographics, learning style, knowledge levels, learning history).

Semantic processing layer – *Semantic search:* Keyword-based search and semantic search over the knowledge graph to retrieve relevant resources (e.g., "Show me a video about solving kinematics problems").

Knowledge output: Reasoning mechanisms for inferring relationships (e.g., "If a student masters algebra, he can move on to calculus").

AI-powered components. *Adaptive learning mechanism:*

- Content development tools for *Personalization* (using machine learning models to recommend content based on student performance and goals) and *Learning Paths* (creating dynamic, personalized learning paths based on knowledge gap analysis and learners' progress through the content.
- Semantic textbooks in various disciplines built on the basis of AI tools [10].
- Tools for assessing the user's abilities, learning preferences, psychology of perception, communicative characteristics, determining methods and technologies for personalized learning taking into account the tasks and goals of learning, etc.

Rating and Feedback:

- Automated assessment: for example, using NLP algorithms to assess essays, papers, problem solutions, code submissions or open-ended responses.
- Competency tracking: identifying the user's (learner's) achievements by matching them with some predefined competencies (e.g. "Can solve linear equations") using an ontology.

Application layer

This layer may include the *User Interface (UI)* for system roles:

- Interface for technical developers with tools for managing data and functions of both the system as a whole and individual users (content developers, trainees, etc.)
- Tools for standards developers, including the ability to conduct collegial discussions and evaluate standards, programs, textbooks, methods and other content of the educational system, determine the direction of development of the education system, etc.
- Portals of educational institutions of different levels.
- Learner Portal: A dashboard showing personalized learning plans, progress, and recommendations
- Teacher tools: analytics dashboards for monitoring class/group performance and adjusting curriculum.
- Content Creation: Tools for educators to develop, tag, and link resources to the knowledge graph.
- Expertise of content and methods of its development.

Integration with existing systems:

- API for connecting to learning management systems such as, for example, Moodle, Canvas or Blackboard [11].
- Single sign-on for user authentication.

Infrastructure

- Cloud/on-premises setup to host knowledge graph and AI models
- Real-time processing of interactions, requests and updates.

When developing the structure and components of the subsystems of each layer, it is also necessary to take into account that access to them should be organized based on the allocated roles of system users. This implies the need to define goals and objectives for each user role, as well as a structural and functional scheme of the user's work in this role, including requirements for the functions of the role, the results of work in this role, the system security, the organization of communications between system participants, etc.

IV. Personal assistant as a main communicative structure of each participant

Currently, there are different approaches to the educational process organizing using information technologies. Combining different approaches into a single system is possible based on compliance with the rules for storing and presenting data in a single format (several formats if necessary), maintaining semantic compatibility between system elements, implementing user self-training technologies in the subsystems of the PA, gradually transitioning existing platforms (systems, applications) and further filling the system with content based on semantic technologies. The latter can also be achieved by developing a kind of translator (interpreter) of existing technologies into a semantic representation.

An important component of each subsystem-participant of the system is the Personal Assistant. It can be defined as a separate class of subsystems of the educational system under consideration, which is a mandatory component for each participant - a person, a technical subsystem, the system itself as a whole. The PA of the technical subsystem is mainly responsible for its communications, i.e. data exchange, processing requests from other system participants, forming its own requests, monitoring processes within its subsystem, analyzing and correcting the subsystem's work, storing data and providing access to them, etc.

In addition to the above functions, the user-trainee's PA may include the following elements of interaction with a person:

- Natural language processing subsystem (NLP) including NLP mechanisms for analyzing queries, feedback and content from developers and users; Recognizing user intent from his request (e.g., "I need help with calculus," "Find an AI course," "Create a new textbook," etc.); Contextual analysis: linking user queries to specific knowledge graph(s) (e.g. mapping "machine learning" to related concepts like "artificial neural networks").
- User interaction subsystem based on video surveillance – recognition of emotions, gestures, images, text, voice and, in general, the user's intentions based on the analysis of his image and the objects he depicts (text, drawings, diagrams, etc.)
- Conversational AI: A chat-bot that uses conversational systems to answer questions, provide hints, and guide the user through the system.

Some issues that require special attention during development. *Data movement:* user data processing should be carried out to the greatest possible extent on the user's devices, which will also ensure greater security of his personal data collected and accumulated by the system during the learning process. *Ontology Maintenance:* Regular updates to the knowledge graph are required to reflect new domains or standards. *Confidentiality and data protection* (including personal data of users) *Interaction:* Compatibility with existing educational platforms. A subsystem for translating data from such platforms into a semantic representation of the system is required, a kind of "translator" into the internal language of the system. *Explainability:* all results of the work of AI-based algorithms must be explainable, i.e. a subsystem of explanations is needed not only in the semantic textbooks on subjects themselves, but also when communicating with users.

The structure and functions of the subsystem "Personal Assistant". This subsystem is one of the most important in the structure of the educational intellectual system. Moreover, a user's personal assistant can accompany him throughout his life, being an assistant and keeper of various types of information - medical, educational, professional, household. The PA as a intelligent system should also be an integral part of any subsystem of the intellectual educational system. It is through the PA that communication between subsystems occurs, data is collected and the internal processes of each subsystem are managed, data is stored and processed. The user's PA can be built into small devices, presumably wearable, such as a smartphone or smart watch, for example. Since the PA contains a database, AI components, a user interface, the device must have high-capacity RAM, high-speed data processing elements, cameras and microphones/speakers, and provide reliable wireless communication. In turn, the algorithms of the AI components must be as resource-efficient as possible. In general, the PA is a whole class of information systems that can be developed for people, information, measurement, technological and other systems that participate jointly in any processes and global systems.

V. A unified platform for the development, operation and advancement of an intelligent semantic educational system

Today, there is a wide variety of platforms and tools available to develop and operate information systems, including learning systems, using artificial intelligence technologies. They make it possible to develop both small applications for solving some problems in the field of education, and distributed systems that provide access to a wide range of educational services. Some of the tools and technologies have been mentioned above. The creation of large distributed unified systems based on rather disparate platforms and technologies complicates the developer's task, administration of such systems, data flow management, data protection, entry into the system at the user level, complicates the adaptation of new elements and structures within an existing system. In turn, a single platform for developing a global intelligent educational system is an important condition for its success not only as an information system, but also as a public, state system. Such a single platform, developed in our country, is the technology of ontological design, production and operation of semantically compatible hybrid intelligent computer systems – OSTIS. In addition to its main characteristics, which are included in the name, there are a number of other advantages of its use as a basis for the development and implementation of a state intelligent educational system. Thus, the OSTIS standard [12]–[14] has been developed and is constantly updated, describing the current technology of design, production, operation and evolution of information systems. The OSTIS technology meets the requirements for the IES considered in this work, in particular, adaptability, interoperability, scalability, communicativeness. Interoperability is one of the most important properties of systems developed in accordance with the OSTIS technology. The project is open, which allows any interested person to both familiarize themselves with the documentation and apply the technologies, models, methods and tools of ontological design of semantically compatible hybrid intelligent computer systems, capable of independently interacting with each other, presented in the standard. This means not only the possibility of using the standard by system developers, but also a reduction in the threshold for a new user to enter the system, adaptation of new elements in the system, ensuring semantic compatibility of both already developed and operating systems and those that will be developed and implemented in the future. The transition to such a single platform will allow for the successful implementation of such projects as an intellectual school, an intellectual faculty/department, an intellectual university, and in the future, an intellectual society.

VI. Conclusion

To achieve high level of national education on the basis of unified information system is possible by automating a number of processes in the education system based on the use of semantic, multi-agent, neural network and other AI technologies, including them in the developed structure of the intelligent education system. One of the most important factors determining the level of intelligence of any information system is interoperability, the ability to form collectives with other individual systems, including people. The level of interoperability of the individual information systems of the entire collective that forms the national intelligent education system should be quite high. The national has to be designed on the platform of OSTIS – the original technology developed in our country, having its standard that meets all the requirements to the interoperable intelligent semantic educational system proposed in the present paper.

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ИНТЕЛЛЕКТУАЛЬНАЯ СЕМАНТИЧЕСКАЯ ОБРАЗОВАТЕЛЬНАЯ СИСТЕМА: НАЗНАЧЕНИЕ И СТРУКТУРА

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В работе рассматривается назначение и структура национальной интеллектуальной образовательной системы. Предложены свойства системы и некоторые требования, которым она должна удовлетворять, а также содержание её структурных слоев. Система строится как интероперабельная, адаптивная, многоагентная, каждый из агентов которой имеет своего персонального помощника (ассистента) в качестве интеллектуальной подсистемы для обеспечения самоконтроля, управления и установления связей и коммуникаций внутри системы и с другими системами. Полученные результаты позволят определить направления развития интеллектуальной образовательной системы национального уровня, а также её подсистем и их образовательного содержания с использованием технологий искусственного интеллекта.

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