Modern Architectures of Intelligent Tutoring Systems Based on Integrated Expert Systems: Features of the Approach to the Automated Formation of the Ontological Space of Knowledge and Skills of Students

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Abstract—The features of the main types of architectures of modern intelligent tutoring systems are analyzed. Special attention is paid to intelligent tutoring systems based on the architectures of tutoring integrated expert systems and tutoring web-oriented integrated expert systems, the basic principles and development technology of which are determined by the problem-oriented methodology for building integrated expert systems and the tools of the AT-TECHNOLOGY workbench. The prerequisites, the results obtained, and further prospects for the automated formation of a unified ontological space of knowledge and skills of students are discussed through the use of tutoring web-oriented integrated expert systems throughout the educational process.

Keywords: intelligent tutoring systems, tutoring integrated expert systems, web-integrated expert systems, problem-oriented methodology, intelligent tutoring, student model, model of ontology, ontological space, monitoring, knowledge, skills

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INTRODUCTION

Currently, promising domestic and foreign research in the field of computer educational technologies is associated with the creation of various tools of intelligent computer tutoring based on the development and use of intelligent tutoring systems (ITS), integrating the whole variety of methods and tools of artificial intelligence (AI) with methods and approaches from other areas, in particular, pedagogy and psychology [3, 9, 16, 18, 19, 21, 28].

Architectures of modern ITS are focused on supporting the solution of problems of intelligent tutoring, which is based on the conceptual and logical interconnection of the processes of individualization, web orientation, and intellectualization [19]; therefore, all methods and approaches to the design of ITS with different architectural typology must meet these goals. However, taking advantage of the popularity of this problem, today there is a process of "noise" of the very concept of ITS, since quite often under the guise of ITS a large number of computerized courses and e-learning systems in various subjects and disciplines are described, including e-learning systems and the creation of numerous commercial courses and programs.

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The historical framework of the emergence and development of the subject area of ITS is usually associated with the period of the 1970s–1980s and linked to the names of Carbonell [6] and later Brusilovskii [4], who formulated a general understanding of ITS as a distinct class of applied intelligent systems, whose architectures provide automated support not only for models of problem domains (PD) but also for student models and various tutoring models. The main objectives of the creation of the ITS were design and development of an adaptive tutoring environment, organization of the diagnostic process of identifying errors in the knowledge and skills of students, formation of a personalized tutoring strategy in accordance with the current situation in the tutoring process, etc.

Various classifications of ITS and approaches to their development began to be actively proposed at the end of the 1980s, and since the 2000s they have received the greatest development, based on the diversity of ITS architectures and the state of the current technological base, determined by the capabilities of the Internet, web tutoring, remote technologies, cloud computing, and other tools. The general analysis of the early period ITS and the evolution of the main paradigms of the development of the ITS are devoted to the work [4, 5, 8, 11, 17, 19, 28, 30, 31] and others.

We consider examples of some characteristic approaches to the construction of modern ITS architectures (without claiming to be an exhaustive analysis of all types of ITS architectures), and then in the context of this work, we will focus on the features of a particular class of ITS—tutoring integrated expert systems (IES) and web-IES.

1. GENERAL CHARACTERISTICS OF ITS ARCHITECTURES AND TOOLS FOR THEIR DEVELOPMENT

In terms of the architecture, composition and structure of the main components and tools of the ITS, several types of basic architectures of the ITS have historically been formed: problem-specific ITS with an emphasis on the specifics of tutoring PDs (in particular, on the basis of expert systems (ES) and expert-tutoring systems); web-oriented ITS (web-based ITS), web-oriented tutoring adaptive systems (web-TAS); tutoring integrated expert systems (IES) and web-IES as full-functional classes of ITS; agent-oriented ITS and ITS based on various architectures of multiagent systems (MAS); ITS based on cloud platform technologies.

ES-based problem-specific ITS architectures, as well as web-based ITS and web-TAS, are not entirely new or unique, since, in accordance with the requirements for ITS, knowledge about the specifics of tutoring PDs, about the learner and tutoring strategies is mainly used here to support a personalized tutoring process for specific disciplines. The greatest architectural diversity is distinguished by agent-oriented ITS [18], the architecture of which includes, for example, the following types of agents: agents of the instructor interface, agent of the tutoring interface, agent of access to knowledge, agent of ontology, agent-coordinator of interactions between agents, etc.

A number of ITS are proposed, in which agents, for example, departments of a university [1], are created taking into account the requirements of service-oriented architecture, the main components of which are repository of educational objects, agent of the student, assessment of the knowledge of the student, formation of individual tutoring programs, personal tutoring environment, methodological support, etc. In other ITS [33], a service-component approach to the system architecture has been adopted to ensure the availability and autonomy of components. The prototype of the MAS network interaction of educational institutions is described in [32].

There has been no significant innovation in the area of software tools (ST) to support the development of ITS and web-based ITS, as the focus is on reengineering and further development of existing tools. As an example, we can cite the family of ST of the MONAP type [9], on the basis of which a number of applied ITS are implemented; for example, in [2], an example of using the web version of MONAP is described, with the help of which subject teachers from the same type of PDs can create their tutoring environments with different didactic characteristics.

The IACPaaS platform [12] has modern capabilities for the implementation of ITS to support the development, management, and remote use of application and system multiagent cloud services (including intelligent) and their components. There is experience in creating on the basis of IACPaaS several ITS for medical professionals [13].

Great prospects of intelligent tutoring were shown by educational IES and web-IES, which since 2008 have been actively used to support the educational process at the National Research Nuclear University, Moscow Engineering Physics Institute (MEPhI), constantly improving and developing. Tutoring IES, developed on the basis of a single problem-oriented methodology for building an IES [22] and supporting its instrumentation—the AT-TECHNOLOGY workbench [22, 23]—are fully functional IES, because, inheriting the fundamental principles of modeling PDs from traditional IES, they also have a scalable architecture that allows expanding the functionality of the IES with the help of additional subsystems providing the processes of constructing models of students, tutoring models, models of explanation, and other tools of ITS.

As the basic architectural solutions used for tutoring web-IES, it is necessary to highlight the development of tools that support web testing of students to identify the current level of knowledge of students on the basis of applied ontologies of courses and disciplines, the organization of web interaction with software components that provide identification of the level of skills of students to solve informal problems (IF problems) [20, 25], and development of adaptive tutoring software environment on the basis of semantic integration of interacting processes of building individual models of students and tutoring in the context of the implementation of a specific curriculum or ontology of educational activities [20].

The special tools of the workbench type (AT-TECHNOLOGY workbench) created for automated support of this methodology are constantly being improved and experimentally investigated in practice, on the basic functional platform of which several generations of ST have already been created that provide, among other things, intelligent support for the development and maintenance of applied IES at all stages of the life cycle [26, 27].

At present, an important place in research and development related to solving the problems of intelligent tutoring using web-based educational IES belongs to ontological engineering. This made it possible to realize the general concept of a single ontological space of knowledge and skills of students and on the basis of the intelligent software environment of the AT-TECHNOLOGY workbench to carry out a cycle of research on the automated formation of a single ontological space of knowledge and skills of students throughout the educational process, in order to build competence-oriented models of graduates in specific areas of tutoring [24].

We consider briefly the existing experience of using ontologies in modern ITS for the implementation of these goals, focusing only on the educational sphere.

2. THE PLACE AND ROLE OF ONTOLOGIES IN INTELLIGENT TUTORING BASED ON THE USE OF ITS IN THE EDUCATIONAL SPHERE

The construction and active use of ontologies is an important feature of the development of modern information systems with a variety of architectural typology, including applied intelligent systems such as ITS, and the number of proposed models, methods, methods, special languages, ST, and platforms is already off the scale (detailed reviews are given in [10, 26]). Depending on the selected criteria, there are numerous classifications of ontologies, the most famous of which is the classification of N. Guarino and D. Fensel based on the levels of commonality of ontological models and the isolation of top level ontologies, ontologies of subject areas (domain), ontologies of knowledge representation, and applied ontologies.

One of the most common areas of use of ontologies is the educational process; however, the scope of ontologies here is mainly associated with automated information systems and traditional computer tutoring systems. Using [24, 26], we consider some characteristic examples, positioning the role of ontologies in the implementation of various ITS architectures.

The project of creating an information and educational space [33] in which an important place is given to ontologies of different types especially in the context of this work has interesting prospects: ontology of the subject area (the semantics of educational objects is created); ontology of educational objects (the management of educational content is provided); ontology of competencies (the sequence of studying educational materials is built).

The option of using the ontological approach in creating distributed ITS based on the MAS technology and the principles of the Semantic Web project was proposed, for example, in [14] as the development of distance tutoring systems. From the perspective of ITS, personalization in tutoring is achieved through ontological models, which are a meta-knowledge for the implementation of individual selection of tutoring materials and are coded in the specialized OWL language.

In general, the typology of ontologies used in the ITS for the educational process is determined by applied ontologies and ontologies of the subject area. In domestic practice, applied ontology of various tutoring courses/disciplines is most often used, for which many different approaches are proposed—from methods of visual structuring of information to methodology of knowledge management for integration of development of many tutoring courses at the departmental and interdepartmental levels [1]. The paper [13] describes an intelligent tutoring environment for the diagnosis of acute and chronic diseases, in which several types of subject ontologies are used.

Quite actively in ITS, ontological representations of models of students are used, being based solely on reflection of the level of knowledge of the student. For example, work [15] describes the ontological model of the learner, on the basis of which the individual trajectory of tutoring is built, and the ontological model of the learner in [34] reflects not only the structure but also the dynamics of the formation of professional knowledge. There are also a number of works on ITS that consider the ontological approach to the creation of tutoring models and learning management systems, for example, [7, 29].

However, even in the most advanced ITS architectures, models of students are mainly considered, reflecting only the levels of mastering of declarative knowledge in specific academic disciplines or acquired competencies, and little attention is paid to the identification of procedural knowledge, i.e., skills/abilities to apply the knowledge gained in practice.

In addition, the analysis of various ITS architectures in the context of using the ontological approach showed that, at present, there are practically no methods and tools that ensure the implementation of automated construction and practical use of a single ontological space of knowledge and skills of students formed throughout the entire educational cycle in specific areas/specialties of graduate tutoring.

Now we will briefly consider the main approaches and features of the implementation of the basic concept of the automated formation of the ontological space of knowledge and skills of students on the basis of a set of models and software tools to support the construction of tutoring web-IES.

3. FEATURES OF CONSTRUCTING MODELS OF STUDENTS ON THE BASIS OF APPLIED ONTOLOGIES OF COURSES/DISCIPLINES

Methodological and technological experience of use in the educational process, supported by the generalized ontology "Intelligent Systems and Technologies" and the current versions of the web-based educational IES, has made it possible to implement to date a complete set of typical tasks of intelligent tutoring, conceptually and formally positioned in early research, in particular, [21], and then specified by the results of experimental software modeling and approbation in real conditions of the educational process at National Research Nuclear University MEPhI [20], namely: individual planning of the methodology of studying tutoring courses/disciplines (concrete definition for each student of the sequence of topics/sections of the course, individual control and identification of "problem areas" and levels of current competencies of students, optimization of individual tutoring taking into account the personal characteristics of students); intelligent analysis of solutions to educational problems (modeling of students' reasoning solving IF problems, identification and classification of types of errors and gaps in knowledge instead of their statement, feedback through dynamic updating of students' knowledge); intelligent support for decision-making in the context of the implementation of the functionality of traditional ES (intelligent assistance at each stage of solving educational problems; explanations of the type "how?" and "why?"; a hint of the next stage of the solution).

The leading role in the implementation of the above tasks belongs to the applied ontologies of courses/disciplines for the construction of current models of students by applying ontologies in the organization of the processes of identifying knowledge and skills of students, carried out in the RunTime mode (intended for the student) in the framework of control measures in the form of web tests, etc.

The knowledge of students is identified on the basis of the use of applied ontologies of courses/disciplines created in the DesignTime mode (intended for the teacher) and the dynamic formation of current competence-oriented models of students, which are based on the analysis of answers to questions from special web tests, diagnosis of knowledge gaps (detection of so-called "problem areas" and current competencies by comparison with fragments of ontologies), and the subsequent formation of individual plans or tutoring strategies using different types of specific tutoring influences. The generation of variants of test tasks is carried out before the start of web testing by applying the genetic algorithm [19] to a given fragment of applied ontology of the course/discipline.

The processes of skills identification, also performed in the Runtime mode, are more specialized and are determined by the currently implemented models of skills/abilities to solve specific types of IF problems for a specific course/discipline and the possibilities of software support for interaction with elements (vertices) of relevant applied ontologies (these issues are discussed in detail in [25]).

Thus, the general concept of the ontological space of knowledge and skills of students from the standpoint of the architecture of the web-based educational IES can be interpreted as a set of all information and educational processes and resources for the implementation of typical tasks of intelligent tutoring during the full cycle of continuous tutoring on the basis of generalized ontology and the tools of the intelligent program environment of the AT-TECHNOLOGY workbench for the purpose of automated construction of competence-oriented models of graduates in specific areas of tutoring. In this case, the automated formation of the ontological space of knowledge and skills of students is essentially a full-functional educational monitoring of the functioning of the tutoring web-IES during the full educational process (considered in Section 5).

4. BASIC MODEL OF ONTOLOGY AND FEATURES OF AUTOMATED FORMATION OF ONTOLOGICAL SPACE OF KNOWLEDGE AND SKILLS OF STUDENTS

Issues related to the development of models, methods, and ST to support the construction of ontologies on the basis of problem-oriented methodology and tools of the AT-TECHNOLOGY workbench were considered in a number of works, in particular, [19, 20, 24]. Therefore, here we will highlight only the most important properties and features that position the place, role, and opportunities of the proposed ontological approach in the development of intelligent tutoring based on the use of web-based educational IES.

1. The general methodological and software support of all processes of construction of applied ontologies of courses/disciplines and generalized ontologies of specialties/areas of training on the basis of a single model of ontology in the form of a semantic network of a special type is provided (formal aspects are described in [19, 20] and other works).

2. Unlike the models of ontologies used in most computer training systems and ITS, the proposed model provides wide possibilities of representation as elements of the semantic network (tops of the network) not only of concepts related to the hierarchical structure of courses/disciplines (sections, topics, subtopics, etc.) but also of various models of competences, as well as models of training influences and models of identification of skills/abilities of students [26]; the ability to display various types of relations between the network vertices not only of the taxonomic type but also of semantic relations reflecting the specifics of the relationships of all elements of the ontology model; and developed algorithmic and support for the implementation of the required functionality in the interpretation of heterogeneous elements of the ontology model.

3. All processes of construction of applied and generalized ontologies on the basis of the basic model of ontology are carried out in an automated mode owing to the development of specialized ST designed in accordance with the requirements of the intelligent software environment of the AT-TECHNOLOGY workbench as reusable components.

4. From the point of view of the architecture of the tutoring IES and the web-IES, the proposed ontological approach is universal, since it not only is used for the construction of applied ontologies of courses/disciplines but also performs an important algorithmic and technological function in the construction of competence-oriented models of students and adaptive tutoring models.

5. Conceptual and integration capabilities of the basic model of ontology allow solving interrelated

complex problems of automated formation of a single ontological space of knowledge and skills of students [24] both in the context of intellectualization of the processes of development of applied IES as a whole [27] and in the context of further development of intelligent tutoring technology based on web-IES, which is achieved using a set of models reflecting a large expert and technological experience in the creation of unique methods, procedures, algorithms, and tools of identifying and assessing the skills of students to solve IF problems, provided for in the framework of generalized ontology as standard tasks of intelligent tutoring, and the totality of the currently implemented tutoring influences of various types, from which specific plans (strategies) of tutoring are formed (described in detail in [19] and other works).

Let us consider some methodological and technological features of monitoring the processes of functioning of web-IES tutoring.

5. DEVELOPMENT OF TOOLS OF MONITORING THE PROCESSES OF FUNCTIONING OF TUTORING WEB-IES AND METHODS OF PROCESSING ITS RESULTS

The traditional view of the problem of monitoring any automated system, including educational monitoring, involves the creation of a system for collecting, storing, analyzing, and presenting information about the state of observed objects, phenomena, and processes for the purpose of their assessment, control, or prediction. In this case, the monitoring of the functioning of the tutoring web-IES is determined by the technology of implementing a set of functional tasks characteristic of intelligent tutoring and in general is associated with the "tracking" and analysis of all processes of building an individual competence-oriented model for each student in the relevant discipline (by identifying the current level of knowledge/skills) and the dynamic formation of the appropriate tutoring model.

At present, it has been possible to ensure the fulfillment of most requirements of educational monitoring by automating almost all processes that arise during tutoring and control of the knowledge/skills of students. At the same time, all information about students, subjects of courses/disciplines, results of tutoring, and results of student control and individual recommendations is in a single ontological environment and at any time is available to the student and/or controller of the tutoring process. Management, analysis, and processing of current monitoring results is provided by the development of special tools of the intelligent software environment of the AT-TECHNOLOGY workbench.

Among the main requirements for methods and algorithms for processing monitoring results, we should indicate the following: the need for constant formation of contingents of students with high and/or low levels of knowledge/skills and competencies; conducting systematic analytical and statistical processing of data on the basis of the introduced parameters; generation of current and final reports (statements) for departments and other departments of the university reflecting competence-oriented models of students, as well as additional information on independent work, the forecast of the final assessment, and other information.

To conduct analytical and statistical processing of monitoring results, basic parameters were proposed, including analysis of "problem areas" of students and their clustering, analysis of the effectiveness of applying an individual tutoring plan by assessing the impact of tutoring influences on increasing the level of knowledge and determining the most appropriate tutoring influences, calculation of the correlation between the level of skills and the level of knowledge on the relevant topics of the course/discipline, etc. For most of these parameters, appropriate methods, algorithms, and special software tools have been developed; others, more complex, are in the stage of preliminary research and will be refined.

When monitoring the processes of functioning of tutoring IES, it is necessary to take into account such factors as the requirements for the reliability and safety of tutoring IES and web-IES, as well as to ensure the control of the copyright of experts (subject teachers) on the knowledge and skills formalized during the development of each specific applied ontology of the course/discipline.

CONCLUSIONS

The general concept of a single ontological space of knowledge and skills of students as an adaptive program environment of intelligent tutoring based on the use of tutoring web-IES was formed on the basis of the development of the basic provisions of the problem-oriented methodology for building an IES, initially focused on powerful integration capabilities in modeling typical IES architectures.

On the other hand, the experience of using educational IES and web-IES in conditions of the real educational process made it possible to develop original approaches and methods for identifying both the current level of knowledge of students and the skills/abilities of students to solve various educational problems, including IF problems. The accumulation of methodological experience in the form of a wide range of implemented tutoring influences of various typologies provided the possibility of dynamic construction within a single ontological environment of individual tutoring strategies (plans), taking into account the diagnosed "problem areas" of students.

In the future, from the point of view of supporting the full educational cycle and the formation of the final competence-oriented models of graduates, it is necessary to significantly strengthen the integration role of generalized ontology, as well as expand the algorithmic and software base for the implementation of educational monitoring of the processes of the functioning of tutoring web-IES.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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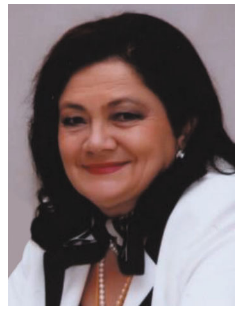

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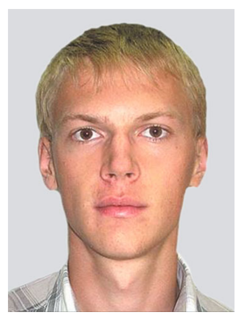

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