

Intelligent Support of Educational Process Basing on Ontological Approach with Use of Tutoring Integrated Expert Systems

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Abstract. Experience of development and usage in education process in NRNU MEPhI of tutoring integrated expert systems is analyzed. These systems are developed basing on problem-oriented methodology and AT-TECHNOLOGY workbench. This work is focused on value, role and peculiarities of ontologies integration with other components of tutoring integrated expert systems.

Keywords: Problem-oriented methodology · Tutoring integrated expert systems · Standard design procedures · Reusable components · Student model · Tutoring model · Ontology model · Basic intelligent tutoring problems · AT-TECHNOLOGY workbench

1 Introduction

Interest in intelligent tutoring systems (ITS) arose at the turn of the XX and XXI centuries, and now they occupy a significant place in a wide scope of intelligent systems issues. Educational sphere is a good “ground” for the application of artificial intelligence methods and tools, giving rise to a considerable number of approaches and system architectural solutions for intellectualization, individualization and web orientation of learning and training processes. Now, there is an “information explosion” of publications both in Russia and abroad on the subject of ITS. Without claiming to be exhaustive in our review of works in the field of ITS, we will mention only a few papers [2, 7–9, 13], reflecting the results of researches that were conducted in NRNU MEPhI and other universities. The laboratory “Intelligent Systems and Technologies” department of Cybernetics at NRNU MEPhI has accumulated a lot of experience in the development and use of tutoring integrated expert systems (IES) based on problem-oriented methodology [10, 15] and powerful modern tools such as AT-TECHNOLOGY workbench [10, 12, 15].

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Tutoring IES and web-based IES (web-IES) are fully functional ITS of the new generation, ensuring the implementation of all the basic models of the ITS (student model, tutoring model, model of the problem domain, ontologies of several types, etc.), as well as the solution of the complex basic intelligent tutoring problems, containing [13, 15]: individual planning of course/discipline study; intelligent analysis of tutoring tasks solutions; intelligent decision support.

Therefore, to support the construction of tutoring IES on the basis of problem-oriented methodology (AT-TECHNOLOGY workbench) was created and tested in practice in the educational process of NRNU MEPhI and other universities special funds that implement “manual” methods of solution of various non-formalised problems, in particular, is presented in [4]. As shown in [13, 15], ontologies and ontological engineering become particularly relevant in the integrated intelligent systems, in particular in the IES, intelligent decision support system (IDSS) and ITS. In then architectures both components as a simple expert systems (ES), intended for solving non-formalised problems and any other components and software implementing solving formalized problems are used together. Here, the main role of an ontology is to create a common basis for the explicit description of the semantics of knowledge and data, which essentially simplifies the integration processes in such systems as the ITS or IES.

By now, there have already been gained considerable experience related to the development and the use of ontologies of different types (top-level ontologies, domain ontologies, representation ontologies, application ontologies etc.), created a number of ways, scripts and methodologies for the appliance of ontologies, developed many languages, tools and platforms for designing intelligent systems based on ontologies. The most detailed and systematic analysis of the models, methods, tools and examples of implementation of the ontological approach is given in [4], as well as these issues are dedicated to [3, 15, 20–22], and others.

The primary focus of this work are questions of modeling of educational activities, in particular the educational process in higher educational institutions, with ontological approach. It is largely attributed to the current stage of the evolution methods of intelligent tutoring and the creation of new ITS architectures based on the ideas of tutoring IES [10, 11, 15, 18], when development of which is based on the problem-oriented methodology and supporting it AT-TECHNOLOGY workbench [10, 12, 15].

Today tutoring IES and web-IES, operate on the basis of generalized ontology [15] “Intelligent Systems and Technologies” and a set of ontologies for specific courses/disciplines. They were created with help of special tools of AT-TECHNOLOGY workbench and basic educational materials provided by the FSES (Federal State Educational Standards).

In general, long-term experience in the development and application in the educational process of NRNU MEPhI of tutoring IES and web-IES is described in detail in monographs [10, 15] and other works, for example, [11, 13, 18], and others. This paper is focused on the methods of integration of ontologies of particular courses/disciplines with other components of the architecture of the tutoring IES, like an individual network student model and adaptive tutoring

model. Their construction is carried out in the context of the requirements of a heuristic model of the solution of the typical education problem, as well as the methods of its implementation by AT-TECHNOLOGY workbench [10, 15].

Another important aspect of research and development in the field of ITS is connected with development of tools and technologies for automated support of ITS development. Currently there is no big diversity and innovation of tools and researchers are focused the focus is on reengineering and development of the existing tools. It should be noted that currently there is no standard technology of ITS development, so workbench of general purpose is often used for ITS, for example, [5, 6, 20] The focus of this work is the further development of methods and tools for automated construction of tutoring IES with use of intelligent software environment components.

2 General Characteristics of the Components of an Intelligent Software Environment of the AT-TECHNOLOGY Workbench

The AT-TECHNOLOGY workbench is a modern tool that supports intelligent software technology for automated construction of IES of different types and levels of difficulty. The conceptual base for the integration of methods of knowledge engineering, ontological engineering, intelligent planning and traditional programming is the concept of “intelligent environments” first introduced in [10] and studied experimentally in the process of developing a number of applied IES, including tutoring IES [10–12, 15, 17, 19]. The basic role in the intellectual software environment belongs to the intelligent planner, which manages IES and web-IES development projects. Different versions of the scheduler are described in detail in [10, 15–17] and other works.

Therefore, this work is focused on questions related to the methods of implementation of the above-mentioned tasks of intelligent training with the help of other, equally important components of an intelligent software environment of the AT-TECHNOLOGY workbench. As shown in [10], the main components of an intelligent software environment used for construction and execution of plans for the development of prototypes of applied IES include standard design procedures (SDP) and reusable components (RUC). In accordance with [10], SDP model for tutoring IES is represented as

$$SDP_T = \langle C_T, L_T, T_T \rangle \quad (1)$$

where C_T is a set of conditions, which ensure SDP invocation; L_T - an execution scenario described with internal SDP actions description language; T_T - a set of parameters initialized by the intelligent planner when SDP is included into an IES prototype development plan. Every RUC, involved in IES prototype development is defined as

$$RUC = \langle N, Arg, F, PINT, FN \rangle \quad (2)$$

N in this model is the name of the component, by which it is registered in the workbench. $Arg = \{Arg_i\}, i = 1...l$ - set of arguments containing current project database subtree serving as input parameters for the functions from the set. $F = \{F_i\}, i = 1...s$ - a variety of methods (RUC interfaces) for this component at the implementation level. $PINT$ - a set of other kinds of RUC interfaces, used by the methods of the RUC. $FN = \{FN_i\}, i = 1...v$ - set of functions names performed by this RUC. The main algorithm element used during development plan generation process of the IES prototype is SDP. By SDP we mean a set of elementary instructions (steps) which are traditionally executed by a knowledge engineer at every development lifecycle stage. The intelligent planner of the AT-TECHNOLOGY workbench has knowledge about all available SDPs, and based on this knowledge it forms a set of tasks for any IES prototype development (accordingly to a current lifecycle stage). Then, basing on special requirements specified at the system requirements analysis stage, the planner decomposes the plan into smaller tasks (subtasks).

All the workbench SDPs are classified in the following manner: problem independent SDPs (for example, “knowledge acquisition from database”), problem dependent SDPs (for example forming tutoring IES components), SDPs related with RUC, i.e. procedures, that contain knowledge about RUC lifecycle from its configuring up to including it into the IES prototype model. Latter SDPs also contain knowledge about problems solved with this RUC and its necessary configurations. The general architecture of the AT-TECHNOLOGY workbench is built in such manner, that all functionality is distributed between the components registered in the workbench and acting under intelligent development environment. In other words, these components are reusable components of the workbench, and they are developed in accordance with some workbench rules [10].

There are SDPs related to distributed knowledge acquisition from different knowledge sources, dynamic IES development SDP and the most complicated SDP for tutoring IES construction [10] in the experimental stage. The difficulties of the tutoring IES development technology are caused by supporting two different work modes - DesignTime, oriented to work with teachers (course/discipline ontology creating processes, different typed training impacts creating, etc.) and Runtime, for working with students (current student model construction processes, including psychological model, etc.).

In the RunTime mode the following AT-TECHNOLOGY workbench instruments are used: training impact construction tools (hypertext textbook, educational-training tasks), basic core workbench tools for IES prototype construction, student psychological model construction tool, tools for course/discipline ontology construction, individual tutoring strategy former, tutoring strategy realization component, different skills level elicitation components, component for mapping a current student model to course/discipline ontology.

The student model construction (student model current knowledge, student model current skills, psychological model components) is directly connected to the tools for construction and realization of the tutoring model, as well as to

the component for mapping a current student model to course/discipline ontology. The mapping component is also connected to the individual tutoring strategy forming component. The peculiarity of a tutoring web-IES developed with AT-TECHNOLOGY workbench is a presence of some components of skill level detection and of the component for construction a student's psychological model (as an aggregate of personal characteristics which are collected as a results of psychological testing).

The most difficult and complicated stage is the construction of the "Training with IES" training impact, which includes a comprehensive problem of the applied IES development for a certain problem. This IES is developed using AT-TECHNOLOGY workbench core. For example, almost all the courses of the "Intelligent systems and technologies" specialization require some knowledge of engineering methods. These methods are presented as non-formalized tasks and non-formalized methods such as "System analysis of the problem domain about applicability of the ES technology", "Choosing knowledge representation formalism", "Choosing development tools" and other tasks requiring expert knowledge [10]. The aggregate of the listed non-formalized tasks and their logical relations are the base for the problem domain construction. The model of problem domain is constructed with the knowledge representation language used in the AT-TECHNOLOGY workbench.

3 Features of Realization of Some Intelligent Training Tasks Based on the Use of Operational and Informational RUC

In accordance with problem-oriented methodology for constructing IES [10], one of the important components of a generalized model of a typical tutoring problem is the network student model, the construction and renovation of which is carried out dynamically by implementing control measures, provided by the curriculum of each course/discipline. For these purposes, as a part of the subsystem of construction of tutoring IES/web-IES, which works in both (basic and web version) of AT-TECHNOLOGY workbench, there are special tools for construction student model.

As described above, the set of SDP and RUC are components of intellectual technological knowledge base [10, 15] providing the intellectualization of the creation and operation of a wide class of ITS, including tutoring IES. Detailed description of the intelligent software environment model and the means of its implementation are given in [10, 15–17, 19]. Specifications of operational and informational RUC's that copes with major issues of intellectual tutoring are presented in this work. Brief description of these RUC's is given below.

Since the models and methods for constructing of training IES and web-IES on the basis of the problem-oriented methodology and the AT-TECHNOLOGY workbench that supports this methodology are described in detail in two monographs [10, 15], we will focus on the analysis of the experience of developing and using training IES in the educational process and creating a single ontological

space in the context of solving basic intelligent tutoring problems. The unifying basis for the basic intelligent tutoring problems [15] is the use of IES of different architectural typology (tutoring IES, ITS on the basis of intellectual agents, etc.) are processes of elicitation knowledge (declarative knowledge of a specific course/discipline) and skills (procedural knowledge that allows to demonstrate how the declarative knowledge of the trainees is used in practice). When these processes are implemented in the tutoring IES (in the RunTime mode), the current competence-oriented student model [10] is dynamically formed, which is based on the analysis of answers to questions from special web tests. Generating of test case variants is performed before the beginning of web testing by applying the genetic algorithm to the specific ontology of the course/discipline or to its fragment [15] in accordance with the curriculum for carrying out control activities.

In the current version of the tools for generating test case variants, the following requirements are supported: the generated question test should cover the specified fragment of the ontology of the course/discipline; in each of the options there should not be the same questions; the number of questions in each option should be the same; the aggregate level of complexity of each option should be approximately equal; So-called “cluster issues” should not be in one version. As for the methodology for evaluating knowledge, it is based on the calculation of the resulting estimate for the complete test (described in detail in [10,15]). Then the current student model is compared with the ontology of the course/discipline, as a result of which so-called “problem zones” are elicitation in the students’ knowledge of the individual sections and topics of the course/discipline and the corresponding current competence. Thus, ontologies of courses/disciplines be key in revealing the level of knowledge of students and construction competence-oriented students models.

Now consider the place and role of ontologies in the processes of computer-based elicitation of students abilities to solve tutoring problems. As it was shown in [10,18], today in the higher educational process two groups of courses/disciplines are distinguished: strongly and medium-formalized (mathematics, physics, theoretical mechanics, etc.) and poorly formalized (non-formalized) humanitarian, engineering and special courses/disciplines. For the first of them, questions of the creation of computer tools reflecting the teaching methodology, the specifics of the requirements for tutoring tasks, methods of evaluation, etc., are well developed and rely on ready-made solutions and standards.

Concerning the second group of courses/disciplines, the situation is much more complicated, since for such unofficial courses/disciplines, the process of elicitation skills to solve tutoring problems is related to modeling the reasoning of the person (student), and other approaches are already required related, in particular, to the methods and means of traditional ES and IES. For example, the tutoring of special courses/disciplines in the areas of training “Applied Mathematics and Informatics” and “Software Engineering” (“Introduction to Intellectual Systems”, “Expert Systems”, “Intelligent Information Systems”, “Intel-

ligent Dialogue Systems”, etc.) is impossible today without elicitation the skills and abilities of students to solve following problems [11, 13–15, 18]: the ability to construct on the basis of the “self-expert” models of the simplest situations of the problem domain based on frames and semantic networks, simulate strategies of direct/reverse reasoning in the ES, construction the components of the linguistic model of business prose sublanguage, and others. The training tasks listed above are based on non-formalized expert methods, the experience of which has been accumulated in the technologies of traditional ES and IES, in particular, in knowledge engineering [4, 14].

As shown in [11, 14, 15, 18], in order to determine the skills/abilities of students to solve the training non-formalized from the six courses/disciplines presented in the generalized ontology “Intellectual Systems and Technologies”, it is used the simulation of the reasoning process of students solving four types of the following training tasks: simulate strategies of direct/reverse reasoning; simulation of the simplest situations of the problem domain with the use of frames and semantic networks; construction components of the linguistic model of business prose sublanguage.

For several years of experimental software research on several generations of students and continuous improvement of the methodical, algorithmic and software of all the above RUC, it was possible to create quite unique methods and software to elicitation and evaluate the skills of students to solve informal practical problems within the ontology of a specific subject area. Since all RUCs were developed and operated autonomously without connection with the corresponding ontology of courses/disciplines, special algorithms and tools were developed to integrate the ontology elements of courses/disciplines with a variety of RUCs to identify the student’s ability to solve tutoring tasks.

Typically, in the context of the ontological approach, a conceptually close problem arose in the construction of an adaptive tutoring model that, in accordance with [10, 15], contains knowledge of the planning and organization of the tutoring process, depending on the individual tutoring models. An important feature is that each strategy (plan) of education consists of a certain sequence of learning impacts of different types, the application of which is completely determined by the state of the current student model (in particular, by “problem zones” and other parameters). At the present time, it were developed, decorated as a RUC and have undergone experimental testing such classes of teaching influences such [10, 15] as the solution of educational-training tasks (ETT) [1] of several types, reading sections of the hypertext textbook (HT-textbook) and “training with ES/IES”.

The greatest expansion of applied ontologies of courses/disciplines was associated with the implementation of the integration of ontology elements of courses/disciplines with a set of the following ETTs, designed as operational RUCs [15]: “Arrangement of correspondences between blocks”, “Filling in blanks in the text”, “Marking or correction of the text”, “Choosing answer options”, “Arranging graphic images”.

3.1 Individual Planning of Course/Discipline Study

Main operational RUCs for this task are the means of construction the ontology of a course/discipline [15]. Also it uses about ten informational RUC's, associated with fragments of HT-textbooks for specific courses/disciplines, and several informational RUC's for construction a generalized ontology "Intelligent systems and technologies".

Each tutoring strategy includes a specific sequence of training impacts such as: reading of a hypertext book; solution of several types of ETT ("Construction relationships between elements of the graphical representation", "Organizing graphics", "Enter a numeric value for the interval", "graphic analysis", "The mapping and sequencing of the blocks", "Formation of the answer by selecting its components from the proposed list", "Marking the correction of the text", "Filling the gaps in the text", "Setting correspondences between blocks", "Enter the answer to the open question"); implementation of training impact "Training with IES"; explanation of the obtained results; tips; localization of errors made; control of the correct solutions, etc. Any tutoring strategy is characterized by a specific set of procedures and application of training impacts, the content of which is determined by the degree of destabilization of the problem, depending on the level of knowledge and skills of a student and his or her psychological portrait. The process of formation and implementation of all relevant tutoring impacts is supported by special operational and informational RUC's.

3.2 Intelligent Analysis of Tutoring Tasks Solutions

To elicitation the skills and abilities of students to solve tutoring non-formalized problems from six courses/disciplines represented in a generalized ontology "Intelligent Systems and Technologies" [14,15] a simulation of student's reasoning for solving four types of learning tasks was used: simulate strategies of direct/reverse reasoning, simulation of simplest situations of problem domain with frames and semantic networks, construction the components of a linguistic model of business prose sublanguage.

3.3 Intelligent Decision Support

It is important to note that in the development of tutoring impacts such as "Training with IES" for different formalized courses/disciplines the most important task is construction of problem domain models (including those based on knowledge, containing certain types of NEG-factors [10]). Another important task is implementation of "consultation with IES" mode, in which there are scenarios of dialogues with the student. In this dialogues a considerable attention is given to explanations, tips and/or verification of the next stage of solving the problem, etc. Here we could apply multiple operational RUC's from the basic AT-TECHNOLOGY workbench (communication subsystem, universal AT-SOLVER, an explanation subsystem, etc.), as the development of training

impact is a task of creating a complete IES. Informational RUC's are also used (knowledge based fragments from previously created teaching operations "Training with IES", fragments of user dialogue scenarios in "Consultation with IES" mode, etc.) and operational RUC "Explanation component" provides assistance at every stage of the solution of educational problems particularly, gives hints of the next stage, gives explanations like "how" and "why" as well as makes at visualization of inference.

4 Conclusion

Educational process automation basing on intelligent software environment of AT-TECHNOLOGY workbench was discussed. Basic components of technological knowledge base of AT-TECHNOLOGY workbench were described including reusable components and standard design procedures. Standard design procedure for tutoring integrated expert systems construction was briefly described in context of ontholigal approach. Basic intelligent tutoring problems and their implementation were analysed. For all three basic intelligent tutoring problems the software components developed for its support are briefly described.

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