Information technologies in the management of technical systems - development of the engineering education

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Abstract. The current level of production development requires the training of qualified specialists capable of solving complex scientific and technical problems in the field of technical systems management using rapidly changing information technologies. Consequently, the training of professional personnel should provide for the needs of developers of advanced control systems for complex dynamic objects. This problem is successfully solved at the Department of Automation and Control Processes (ACP department) in ETU "LETI". Students training is carried out in two complementary directions "Management in technical systems" and "Information systems and technologies". Long-term experience proves the advisability of choosing such an approach in the context of rapidly developing technologies. The report contains studies based on the application of data analysis methods and models that dynamically integrate the information necessary for adaptive management of the process of advanced specialists training. The dataset includes: actual employers' data, production needs, on the one hand, data obtained during the educational process, on the other hand. At the same time, the data set includes data that enable students to assess the effectiveness of the educational services provision, the level of professional training in the areas of specialty. Comprehensive analysis of data integrated in a unified environment, based on the methods of intelligent systems, analytics and knowledge engineering, proves the validity of choosing this approach in the learning process.

Introduction

In the conditions of modern reality, the successful existence and competitiveness of a higher educational institution directly depends on the effectiveness of the educational services provision. In addition, great importance is attached to the timely and quick response of an educational institution (university) to the needs of developers of industrial facilities of complex technical systems. This confirms that the training of highly qualified specialists should be ahead of schedule in this rapidly developing digital age, in which IT technologies are the main conductor. There is an urgent general need for fundamental changes in education, also driven by modern e-learning tools, services and information technology.

The relevance of the educational direction development focused on the comprehensive implementation of information technologies in the management of technical systems is due to a number of documents, for example, the provisions in the Decree of the President of the Russian Federation of May 9, 2017 No. 203 "On the Strategy for the Development of the Information Society in the Russian Federation for 2017 - 2030". The strategy especially notes: intensification of the use of
technologies (p. 12); widespread introduction of data processing technologies (p. 14); improvement of knowledge sharing mechanisms (p. 26, e); the need to use and develop various educational technologies ... (p. 26, i) ".

The implementation of the noted provisions is seen in fundamentally new approaches to managing the process of training highly professional specialists in the areas of "Management in technical systems" and "Information systems and technologies" on the basis of actual monitoring, comprehensive data analysis, forecasting the trajectories of "growth" of the knowledge level, taking into account both subjective preferences and the personal students characteristics, as well as the influence of external factors - changes in the employers requirements, an increase in computing power, which is possible with the use of methods of intellectual analytics and artificial intelligence technologies.

The report presents the analysis results of the students' training state according to the noted programs, presents the results of research, and identifies the prospects for the development of training areas.

1. Features of training specialists in the areas of "Management in technical systems","Information systems and technologies."

At the St. Petersburg State Electrotechnical University "LETI" at the Department of Automation and Control Processes (ACP), students are trained in two complementary areas "Management in technical systems" and "Information systems and technologies". The training of students is based on the idea of developing and integrating two educational areas due to the focus of educational processes on the comprehensive use of digital technologies and artificial intelligence technologies.

The level of development of the educational direction is associated with the following features:
1. development of new concepts and methods for managing complex dynamic objects;
2. the use of modern information technologies in the development of control systems for technical objects.

These features determine the focus in teaching disciplines in the field of management systems towards the use of new educational methods, the implementation of individual trajectories of training for specialists.

In this regard, the experience of integrating two educational areas is promising: "Management in technical systems" and "Information systems and technologies". The many years of pedagogical experience of the authors and the staff of the department proves the advisability of choosing such an approach in the context of rapidly developing technological progress.

The university constantly conducts surveys of employers and students, which assess the learning process, educational content, and the teachers work. On this basis, the further direction of the development of the educational direction is formed.

Analysis of the results of surveys of students and employers confirms the correctness of the chosen direction of development of ACP department in the field of training. This is especially evident in the senior undergraduate and graduate courses. The employers' demand for such specialists is almost 100% [1, 2].

Consequently, the obvious prospects for the development of complementary areas of training for students also require fundamental changes in teaching courses using modern e-learning tools.

1.1. Training tools.

The intensive development of technologies for electronic and blended forms of education (E-learning, Blended Learning) has contributed to the application of a dynamic approach to managing the formation of the professional potential of students. It has become possible to apply dynamic systems and mathematical modeling to the study of complex organizations, such as educational systems aimed at increasing the efficiency of interaction between educational institutions, consumers of educational services and consumers of qualified personnel.
Revealing the significance of development indicators of highly professional specialists in the learning process is based on research in the fields of pedagogy, didactics, management science, which include experimental, theoretical, research, methodological focus on obtaining new knowledge about the basic laws of the functioning and development of learning processes in a changing educational environment under the influence of digital technologies.

The tools for training specialists in the field of science-intensive technologies require the use of virtual laboratories, real processes models, software tools and tools that are actually used at objects in industrial systems, in control systems for complex dynamic objects based on the latest IT technologies.

An important aspect of the application of modern approaches in teaching is the tools for building individual trajectories and intellectualizing the process of preparing students. Individual development and cognitive growth are the key changes in understanding the modern educational environment. A dynamic approach, a client-oriented approach to the professional, cognitive and personal development of students, the collection and intellectual analysis of educational data changes the architecture and functional content of the modern educational environment towards expanding the possibilities of operational changes in the course of managing the educational process [3]. Some publications deal with the adaptation of human-machine interaction in modular e-learning systems [4, 5].

At the ACP department, tools have been developed that allow the formation of an individual approach to learning, taking into account the weak and strong factors, methods of assessment, analysis and design of educational activities based on the technology of adaptive learning [3]. It should be noted that the developed tools deal with dynamic adaptation. The ideas of dynamic adaptation were prepared by previous generations of researchers in the field of education (for example, thanks to models that have been proposed as an explanation of the mechanisms of human learning [6, etc.]). Currently, thanks to the development of intelligent technologies, multi-agent systems, methods of data mining, it is possible to implement the above approaches.

1.2. Some research results.
Carrying out a complex of studies on the formation of the professional potential of a digital economy specialist, influencing environmental factors on its development, includes the creation of Data Set and Knowledge Bases based on monitoring the results of learning and vocational training processes using new effective methods of managing poorly formalized transfer processes knowledge, methods of data mining, electronic data warehouses, methods of machine learning, process mining methods, knowledge extraction (KDD, knowledge discovery in databases), text analysis (Text Mining methods), an agent-based approach, which are the most effective tools for the development of intelligent systems in the field of education and training of specialists (Intelligent tutoring systems - ITS).

Research results of the educational process have shown the need for:
- strengthening the value of students' research activities in the learning process on real models, as close as possible to complex technical processes;
- creating an infrastructure to support innovative activities of students, complementing theoretical knowledge with professional skills;
- integration of "traditional", "classical" disciplines in the field of technical systems management with the latest IT technologies, tools for modeling dynamic processes, knowledge engineering methods, software tools, intelligent environments;
- orientation of curricula towards enhanced broadcasting of innovations aimed at advanced development of scientific and industrial sectors;
- integration of the two directions in order to expand the formation of professional competencies of students, focused on the development of cognitive, educational, research, project, scientific and practical activities, on the one hand, and at the same time, a more specific consideration of individual preferences in training, on the other hand.

These features of the educational process can be taken into account by developing models of adaptive training programs based on knowledge engineering methods using the ontological approach. These methods allow for continuous monitoring of the learning process, data collection, feedback
from students, analysis of relevant data on qualification and professional requirements from employers.

2. **Formalization of the educational process procedures based on the ontological approach**

The need to increase the productivity of student learning in distance e-learning (EL) format initiates the development and use of new tools for organizing the educational process and information resources.

One of the promising directions for the development of the EL model (Learning 3.0) is the development of educational ontologies that allow for semantic integration, joint creation and use of heterogeneous information resources [7, 8]. The formal ontological description of the educational process procedures provides the basis for the implementation of planning algorithms and adaptation of individual trajectories of student learning to changes in the educational environment, professional requirements of employers, goals, level of knowledge and cognitive styles of students [9].

At present, international organizations are developing ontologies of the educational process, describing organizational structures, roles of participants, courses, modules, theoretical and practical training resources. For example, Academic Institution Internal Structure Ontology (AIISO) (vocab.org/aiiso), Participation (purl.org/vocab/participation/schema), FOAF (xmlns.com/foaf), AIISO-Roles (purl.org/vocab/aiiso-roles/schema). Ontology Metacademy represents an interconnected network of concepts, each of which is provided with a short description, a set of learning objectives, an estimate of the time to study the prerequisites of necessary knowledge, and pointers to learning resources (metacademy.org). As one of the stages in the development of ontologies, the use of Conceptual Maps (CM) and Mind Maps (Mind Map) is considered as a means of organizing key concepts in the structure of knowledge representation, connected by semantic relations [10 - 13].

Despite significant theoretical and practical advances in the development of the ontological approach, the issues of creating integrated ontologies of the educational process have not yet been sufficiently studied. The proposed report is devoted to solving the problem of developing a multilevel ontology for formalizing the procedures of the educational process.

2.1. **Integration of processes and resources**

The approach involving the integration of two educational directions "Control in technical systems" and "Information systems and technologies" is aimed primarily at the advanced training of highly qualified personnel for the digital economy, at training specialists capable of solving complex scientific and technical problems in the technical systems control.

2.1.1. **Multilevel ontology of the educational process.** The developed approach to the creation of the educational process ontology is distinguished by the integration of three levels of structure, which required the separation of user rights to create, edit, view and use (by methodologists, administrators, teachers, students and other users).

At the top level of the ontology, semantically related requirements for the organization of the educational process are presented, determined by standards, curricula, work programs of disciplines, timetables, etc. At the middle level, ontologies of academic disciplines are presented, integrated with electronic educational information materials and distance learning systems. At the lower level, students are given the opportunity to explore and form educational ontologies, personal ontological knowledge bases with the organization of consulting and methodological support for the analysis of semantic links and adaptive planning of the sequence of knowledge acquisition processes (for example, during independent work).

The information presented in the ontology at the level of individual curricula reflects the "disciplines of choice" of students for more in-depth study in the direction of specialization, performing research work, preparing term papers and final qualifying work.

The lower-level ontology represents the student's expandable personal knowledge base. The planning of the individual trajectory of a student's learning at this level is carried out taking into
account the current level of knowledge of the prerequisites necessary for the implementation of the processes of mastering new knowledge domains - concepts, terms, their definitions, dependencies and relationships. Students are given the opportunity to choose information resources from an expanded bank of hyperlinks to the main sources of information and additional resources of their choice. Depending on the personal cognitive-style characteristics and preferences, the student chooses resources for study, which are provided in an accessible form and of various modalities: books, study guides, electronic textbooks, distance learning courses, videos, etc.

2.1.2. **Ontology development tools.** For instrumental support of the educational process ontologies, a network software package Ontomaster-Ontology has been developed [14]. Knowledge representation is carried out using classes, properties, individuals and data values in the OWL 2 ontology language (international standard Web Ontology Language). When creating a multi-user Web-based learning environment, a multi-agent approach was used, which provides scaling with a number of users, changing work scenarios, actively interacting with users using a notification system and processing requests to ontological knowledge bases. Figure 1 shows a fragment of the ontology of the specialty "Control in technical systems" (CTS), corresponding to the results of a search query for the keyword "adaptive control".

![Fig. 1. Fragment of the educational ontology](image)

The structure displays elements that actualize the presentation of the learning process, semantically related to the concept of "adaptive control". On the left side of the diagram, the visualization of the ontology in the form of a tree is used with navigation through several categories of the learning process: the direction of training, formed competencies, space-time constraints, structural organization, the name of the discipline, etc.

The network software complex OntoMASTER developed by the authors was tested in the development of multilevel ontologies of student learning processes in the directions of "Information Systems and Technologies (IST)" and "Information Technologies in Control (ITC)" at the Department of Automation and Control Processes at ETU "LETI".

2.2. **Advance preparation**

Ontologies are the basis for representing the structures of knowledge domains. Ontology design is a multi-stage process involving a number of specialists: analysts, experts in knowledge domains, knowledge engineers, linguists, etc.
2.2.1. **Automated requirements analysis of the professional competence market.** Ensuring the quality of targeted training of highly qualified personnel is a complex task. One of the topical directions for solving this problem is the improvement of adaptive management of the learning process based on ontologies and predictive models with feedback.

To analyze the professional competencies in demand on the market, the Ontomaster software complex was used based on the method of automated employers needs monitoring.

The method allows you to form and dynamically update frequency dictionaries, thesauri and ontologies of terms, technologies and tools. Ontologies are developed in accordance with the standards of the Semantic Web using the Protege and OntoMASTER-Ontology tools [15].

The ability to operate with big data, to receive the necessary information from them on time, the possession of methods of working with knowledge determine the qualifications of professional personnel. The training of highly professional specialists involves the creation of a system of continuous replenishment and analysis of information resources based on knowledge engineering methods and semantic technologies. An obvious contribution can be the development of basic ontologies of knowledge domains that integrate dynamic knowledge bases of interdisciplinary areas into a single knowledge space. The solution to this problem is necessary both for the training and retraining of graduates who have received education in the relevant areas and specialties, and for obtaining additional competencies necessary for conducting scientific research and expanding their range in related fields. The active use of interdisciplinary ontologies of knowledge domains in the learning process also presupposes advanced training of the teaching staff.

2.2.2. **Ontologies of disciplines.** Ontologies of disciplines contain a formal description of the concepts of the subject domain, their definitions, examples of their use in information resources (in particular, in the corpus of documents, publications, annotations), lexical and semantic relations.

In view of the need to create expandable ontologies of interdisciplinary knowledge domains, a stage is required for defining the goal and concretizing the application of the ontology (educational basic, expanded professional, highly specialized professional).

An example of the structure of the ontology of the knowledge domain "information signals" includes:
- an ontology of signal processing methods: a dictionary of digital signal processing (DSP) functions and their parameters in various implementations;
- ontology of image processing methods: a dictionary of digital image processing functions (Image Processing Toolbox) and their parameters in various implementations;
- ontology of events: a dictionary of objects, their states, events and processes characterizing transitions between states, classification of states in terms of sensor monitoring tasks;
- ontology of machine learning methods: dictionaries of clustering methods, pattern recognition, classification, as well as implementation options.

2.3. **Discussion**

An approach to formalizing the procedures of the educational process using multilevel ontologies in an EL environment is presented. Teachers and methodologists are given the opportunity to flexibly structure the teaching materials of the taught disciplines. Students have the opportunity to choose information resources in order to adapt personal training programs. Depending on the personal cognitive-style characteristics, the level of knowledge and preferences, the student can choose individual resources with the provision of consulting and methodological support.

Intellectual support of learning processes is carried out by means of the developed network software tool OntoMASTER. When creating a multi-user environment, a multi-agent approach was used that allows scaling in the face of a changing number of users, changing work scenarios, actively interacting with users using a notification system and processing requests to ontological knowledge bases. Further research is planned to be continued towards the development of methods and programs for the automated creation of ontologies.
The main perspectives of an integrated approach of two directions of education are that they can instantly adapt educational content and form and teaching technologies to the changing external needs of the professional environment, taking into account the internal individual needs of the individual student.

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