Computer technologies for forming professional competences in Applied mathematics

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Abstract. The article is devoted to the use of computer technologies for forming the professional competences. We describe the study of basic and special courses for bachelor's or master's degrees in the field "Applied mathematics" at the Moscow Aviation Institute (National Research University). All kinds of practices during the study are considered. The continuous forming technology of professional competences at each stage of study with using the computer technologies is shown.

1 Introduction

To form the Federal State Educational Standards of Higher Education based on the competence approach it is determined the list of competences that young specialists should have [1]. This allows creating a list of academic courses and tools that provide these competences and creating methodologies and criteria for determining objectively the accordance level of study with respect to requirements of specified competences.

The competence is the ability to apply knowledge and skills to a successful activity in the chosen field. Results of the education for this approach are no longer formulated in terms of knowledge, skills and abilities, but in the form of competences [1–3]. The competence model of the graduate in the Federal State Educational Standard of Higher Education is the most important requirement. Within the "National Research University" framework the Moscow Aviation Institute has developed the Self-Established Educational Standard with the requirement structure similar to Federal State Educational Standard. It allows performing requirement in terms of ensuring the education quality [4]. The list of courses and their study order may be changed, but the competences from the Federal State Educational Standard must be required [1, 2].

The main goal of this article is to describe the education system at the Moscow Aviation Institute within the "National Research University" framework.

The rest of this article is structured as follows. The next section provides detailed description of the learning process for bachelors and masters at each stage of study with using the computer technologies. The section lists all basic and special courses, as well as all types of practices in the learning process. The final section presents the conclusions for this article.

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2 Forming professional competences

Graduates with bachelor's or master's degrees should have professional competences corresponding to professional activities such as researches, technological processes, the organization and management.

To provide them, students, starting from the first year, in the study of basic courses such as:

- Complex Analysis;
- Control Theory;
- Discrete Mathematics;
- Linear Algebra and Analytical Geometry;
- Mathematical Analysis;
- Numerical Methods;
- Optimization Methods;
- Ordinary Differential Equations;
- Partial Differential Equations

apply computer technologies for laboratory works and courseworks with studying the new algorithms, techniques, methods and with using the textbooks in traditional and online forms [5].

The Moodle learning platform [6] is used to teach students in all basic courses. This platform has become most relevant in the past 2 years due to the Covid-19 pandemic, since training is partially or completely carried out remotely. In the Moscow Aviation Institute, the learning management system based on Moodle contains necessary educational materials, videoconference services, etc. To assess the knowledge level, both intermediate and final testing are used.

Let us describe the technology for preparing tests, which provides the automated generation of variants and filling the bank of questions for testing for basic courses. A special program is developed by Delphi or C/C++ programming language (the choice is not limited to the listed ones) that generates tasks with numerical parameters that cover all themes of the studied discipline. For this purpose the LaTeX format with syntax defined in the moodle package is used. Numerical parameters are set either by a deterministic algorithm or randomly. Different types of questions are used: multiple choice, numerical, matching, etc. The answer options in multiple choice questions are formed in such a way as to minimize the possibility of guessing the correct answer. Using the LaTeX translator the question file is converted into an XML file, which is imported into the learning platform Moodle, and a PDF file (documentation for tests). This technology allows one to create tests for basic courses with a large number of questions, minimizing repetitive options for different students, with a set of correct and incorrect answers, including complex math formulas.

To ensure the technological processes activity the graduates should have the ability to use standard applications for solving the practical problems. Graduates should be able to debug and to test software, to have knowledge of modern programming languages, operating systems, office applications, methods of the data management, principles of operating systems. Such knowledge at the Mathematical Cybernetics Department of the Moscow Aviation Institute is provided by following special courses [7]:

- Computer Linguistics and Information Technologies;
- Development of Information Systems;
- Hypertext Technologies in Information Systems;

- Intelligent Systems;

- Languages and Technologies of Information Exchange;

- Professional Software Environments.

The content of these courses covers a wide range of issues related to the possession for currently available means of creating hypertext systems, principles of intelligent systems and modern mathematical methods used for the development of information systems. The content is also covers issues related to the ability for solving the problems of the knowledge representation and knowledge processing as well as the computer linguistics.

The organization and management activity assumes that graduates are capable and ready to solve practical problems, to take the responsibility, to determine economic expediency of technical and organizational decisions.

The mandatory participation of students in the researches develops abilities to work independently. Students participate in researches from the second year of study and sometimes from the first year of study. They should make presentations about their research work at student scientific conferences and they can participate in student scientific competitions.

The research activity involves the ability to identify the essence of science problems arising in the professional work, the willingness to use mathematical tools for solving the practical problems. It also involves the ability to apply the appropriate mathematical model and to check its adequacy, to analyze results of modeling and to make a decision based on these results.

Such competences correspond to following special courses [7]:

- Analysis and Synthesis of Nonlinear Stochastic Systems in Aviation Technology and Economics;

- Application of Global Optimization Methods in Control Theory;

- Computer Methods in Control Theory Problems;

- Information Technologies in Decision-Making Theory;

- Mathematical Methods for Synthesis of New Control Systems Classes;

- Methods of Solving Problems for Information Processing;

- Modern Theory of Optimal Control;

- Operations Research;

- Optimization of Hybrid Control Systems;

- Prediction of States in Dynamical Systems.

The content of these courses associates with the use of mathematical methods and mathematical modeling on computers to perform laboratory works and courseworks.

In the course "Information Technologies in Decision-Making Theory" it is proposed to use the software for the aggregation of preferences. This software has been developed at the Mathematical Cybernetics Department of the Moscow Aviation Institute and it can also be applied in the course "Discrete Mathematics" [8, 9], since the described algorithms are based on procedures of the graph theory.

When forming the methodologies and criteria that allow objectively determining the compliance level for students to requirements of specified competences it is necessary to rely on all kinds of practices: educational, computational, research and pre-diploma as well as courseworks, which allow evaluating how students can use the gained knowledge for solving the practical problems.

Students after the first year of study have the educational practice. Its purpose is to teach students the use of special mathematical packages for solving the practical problems. At

the educational practice the students learn to use computer algebra systems such as Mathcad and Matlab. Further, these knowledge and skills will be used in the courses "Analysis and Synthesis of Nonlinear Stochastic Systems in Aviation Technology and Economics" and "Computer Methods in Control Theory Problems" that involve the use of the spectral form of mathematical description for the complex control systems [10].

The main goal of the computational practice is to summarize knowledge gained in two years of study. Students should apply mathematical tools for solving one of the practical problem and should develop computer programs on the specified programming language for calculations.

The research practice takes place after the third year of study. It allows not only to write a computer program for calculations that arise in a lot of practical problems, but also to formulate a mathematical statement of the problem as well as to analyze the data obtained from calculations.

Each practice brings the student closer to the final stage of study. The last but one stage is the pre-diploma practice, for which students usually takes place at the company or enterprise. They get acquainted with the research subject, algorithms for solving practical problems and learn to work on a team. The final stage of study is the thesis and its defense. Students get a task at the company or enterprise, where they will start a career. They can also receive a task related to the practical problem at the Mathematical Cybernetics Department of the Moscow Aviation Institute.

Graduates of bachelor's degree should publicly defend the thesis with demonstrating the ability to formulate a mathematical statement of the problem, to describe the mathematical model, to explain methods for solving the problem, to make the computer program for calculations and to analyze obtained results. They should see the progress of their work and practical applications in the workplace thereby demonstrating the professional competences obtained as a result of the special courses study. The bachelor's degree is only the first stage of a specialist formation.

Graduates of master's program to ensure research activities should have the ability to develop and to explore mathematical models of objects, systems, and processes, to develop software, to provide scientific experiments, to evaluate the research results. These competences are supported by the study of special courses [7]:

- Analysis and Synthesis of Nonlinear Stochastic Systems in Aviation Technology and Economics;

- Application of Global Optimization Methods in Control Theory;

- Applied Methods of Optimization and Information Processing;

- Computer Linguistics and Information Technologies;

- Information Security;

- Information Technologies of Decision-Making Theory;

- Intelligent Systems;

- Languages and Technologies of Information Exchange;

- Methods of Solving Problems of Information Processing;

- Modern Technologies for Parallel and Distributed Programming;

- Modern Theory of Optimal Control;

- Optimization of Hybrid Control Systems.

With these courses the students get knowledge about new directions of computer technologies: features of modern SQL and NoSQL database management systems, languages

and technologies of the information exchange based on XML, intelligent analysis of big data based on data mining and machine learning algorithms, computer linguistics, decision-making theory, principles of the symmetric and asymmetric encryption and their using to protect information. Students use electronic signatures for their practical works and coursework.

The study of special courses includes laboratory works and courseworks. Laboratory works is carried out in display classes and require not only theoretical knowledge, but also the ability to work with special mathematical software (e.g. computer algebra systems), to make practical decisions and to analyze obtained results.

Let us show the practical applicability of the for forming the professional competences by the laboratory work "Search for Association Rules" in the course "Intelligent Systems". When performing this work, students receive the analyzed dataset and perform a preliminary transformation to apply the Apriory method. Then they apply this method by two stages:

(1) search for frequently encountered sets of elements that meet the minimum level of minimum support *MinSupport* offered by the tutor;

(2) generation of the found frequently found sets of association rules that satisfy the minimum level of the minimum confidence *MinConfidence* also proposed by the tutor at the initial stage of solving the problem.

Next, students analyze these association rules and change the above values of the indicators to obtain interesting rules. Then students repeat the stage (2) of the algorithm, changing *MinConfidence* to the *Lift* and *Leverage* indicators. Performing such work allows students to form the ability to make decisions, draw conclusions about the applicability of methods and analyze results.

To ensure the technological processes activity the students should be able to analyze and to synthesize complex control systems, for which they should be able to make the scientific and technical documentation, scientific and technical reports, and reviews. To do this, there are exists different forms of studying such as courseworks and both practices research and professional. In courseworks and practices the students, getting a new task, should independently look for ways to solve it, showing its relevance and novelty. Students should develop a computer program and should analyze obtained results. Then, they also should make a report on the problem solution in the form of abstracts at the scientific conference or research articles (see, for example, [11–14]).

Knowledge and skills obtained during all kinds of practices are applied by students in courses "Prediction of States in Dynamical Systems" and "Methods of Solving Problems of Information Processing" with respect to solving the optimal filtering and prediction problems in complex dynamical systems [15–18], and especially in courses "Application of Global Optimization Methods in Control Theory", "Optimization of Hybrid Control Systems", "Mathematical Methods for Synthesis of New Control Systems Classes", and "Modern Theory of Optimal Control", in which various modern models and methods of the optimal control are considered [19–25]. These knowledge and skills are also very important for courses "Computer Linguistics and Information Technologies", "Information Security", "Intelligent Systems", "Languages and Technologies of Information Exchange", and "Modern Technologies for Parallel and Distributed Programming".

One of the significant task in the training is the mastery of modern instrumental software by students. This software may require programming skills in modern languages and may not require special skills. The software used in the training may be free to distribution or proprietary if the training process does not violate the restrictions on its use. In many cases, proprietary software allows the noncommercial use for the training. Therefore, for laboratory works the students actively use Microsoft SQL Server Management Studio [26] to

study capabilities of modern database management systems working with XML or full text data. Students use XML processors to perform laboratory works on validating XML documents, generating XSD schema, creating XPath queries, XSLT and Schematron scripts [27]. The study of machine learning algorithms is provided by using Python [28] with following libraries: Scikit-learn, Numpy, Pandas, Matplotlib, etc. Students widely apply machine learning platforms such as Weka [29] and Knime [30], which do not require programming skills.

The master's thesis ensure the competence of the organizational and management activity, including the willingness to take the responsibility for decisions, to make non-standard decisions and to solve problem situations. On the master's thesis defense the students make a report on the work results, answer questions from members of the State Examination Commission (Thesis Committee) demonstrating that they can take the responsibility for their decisions and can solve problem situations.

3 Conclusion

The article provides detailed description of the learning process for bachelors and masters in the field "Applied mathematics" at the Moscow Aviation Institute within the "National Research University" framework. The main focus is on using the information technologies in the learning process. The study of basic and special courses for bachelor's or master's degrees is described. All kinds of practices during the study are also considered. The continuous forming technology of professional competences at each stage of study with using the computer technologies is shown.

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