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METHODOLOGY OF COMPUTER-ORIENTED TEACHING OF DIFFERENTIAL EQUATIONS TO THE STUDENTS OF A HIGHER TECHNICAL SCHOOL

Abstract. The article proves that effective training of students of the higher technical school in differential equations can be achieved through the development and implementation of a computer-oriented practical training methodology. The methods, forms, and tools of training are described. The use of an educational site and the educational book «Computer-oriented practical exercises on differential equations» is proposed to contribute to the formation of students' abilities to work with ICT, which allow them to develop skills for creating mathematical models, apply procedures for solving differential equations and their systems, and involve software for analyzing and solving certain models. The goals of training were specified, the use of computer-oriented organizational methods and forms of training were proposed when describing the methodology. Implementation of the methodology involves using the developed system of tasks (mathematical, practical, professionally oriented), which promote conscious use of knowledge and skills to apply differential models in students' future professional activities. The results of the experimental verification of the developed methodology of computer-oriented practical training in differential equations are presented. Indicators of the evaluation of the effectiveness of implementing the developed methodology in the learning process were: levels of mastering certain academic skills by students, levels of forming students' skills in mathematical modelling and skills necessary for professional activities of future specialists, in particular, their abilities to use information and communication technologies.

Keywords: differential equations; computer-oriented teaching; higher technical school; mathematical modeling.

1. INTRODUCTION

The problem setting. The vector of higher education reforms in Ukraine is aimed at training future specialists who correspond to the European STEM programs (Science, Technology, Engineering, and Mathematics) [1]. These programs focus on the importance of improving the mathematical education of students.

The differential equation (DE) is one of the fundamental mathematical disciplines, which provides ample possibilities for training students as future scientists and engineers. One of the factors that should have a positive impact on the efficiency of DE teaching is the use of educational innovations and modern tools of information and communication technologies (ICT).

Analysis of recent studies and publications. Such researchers as B. Collis, and J. Moonen [2], T. Leighton [3], P. Mell, and T. Grance [4], A. D. Scott [5], L. Tami, and H. Orit [6], J. G. Harvey [7], J. Shader [8], G. E. Mikhnenko, and Y. Absaliamova [9], Y. Tryus [10], O. V. Dubinina, and L. D. Hrytsiak [11], M. P. Shyshkina, and M. V. Popel [12] are pointing to the constant development and spread of ICT use in the learning process. Scientists confirm positive influence of such technologies on students' academic performance, but do not draw much attention to the use of the above mentioned technologies for mastering students' certain learning skills (applying procedures for solving various types of differential equations of the first order, higher orders and systems of differential equations), mathematical modelling skills and ICT competencies.

The analysis of the works of researchers mentioned above confirmed the importance of improving the methodological system of training higher technical school students. Its implementation in the process of learning DE requires the use of multiple approaches to teaching, such as student-centered, activity-based, and competency-based ones.

Compliance with certain principles of these approaches determines the feasibility of developing a computer-oriented teaching method. This clarification involves adjusting the objectives, contents, methods, forms and tools of training. The necessity to improve the components of the method indicates the relevance of this study.

The hypothesis that the achievement of the above-stated objectives of teaching students DEs can be reached through the development and implementation of a computer-oriented methodology lies in the basis of our research. It is based on the fact that students' active use of the gained knowledge in the process of studying mathematical disciplines has to take place in the process of computer-oriented practical training.

When studying DEs, practical classes should provide forming of students' abilities to work with ICT that enable the development of their skills to create mathematical models, apply procedures for solving differential equations and their systems, and involve software for analyzing and solving certain models. From our point of view, the effectiveness of students' training and professional activities with ICT support increases on condition of positive growth of the levels of formation of these actions.

The aim of the research is to develop the methodology for the computer-oriented practical teaching of differential equations to students of the higher technical school and an experimental test of its effectiveness.

2. METHODS

Students majoring in «Computer Science and Information Technologies» of Donbas State Machine-Building Academy (95 students), the Institute of Chemical Technologies (Rubizhne) of East Ukrainian National University of Volodymyr Dahl (79 students), Vinnytsia National Technical University (86 students), Priazovsky State Technical University (97 students), Kryvy Rih Metallurgical Institute of National Metallurgical Academy of Ukraine (75 students) were involved in an experimental verification of the effectiveness of the developed methodology. On the whole, 432 IT Bachelor students took part in the experiment.

According to the requirements of the pedagogical experiment, experimental (219 students) and control groups (213 students) were formed. During the pedagogical experiment, the reliability of the obtained results was ensured by the following factors: observations in the groups were conducted according to a pre-designed program in the conditions of natural educational process;

students of the control and experimental groups were studying similar in content training material; tests in the experimental and control groups were carried out simultaneously; all measurements were made on the basis of uniform questionnaires, tests, and assessment papers; the teachers involved in the experiment were previously acquainted with the methodology developed by us. At each stage of the experiment, we conducted a systematic analysis of the results of the students' training in DE, correction, and improvement of the methodology.

During the search stage of the experiment, we developed a computer-oriented methodology for teaching DE. According to the methodology, the objectives of the training were directed at the fundamentalization of the training of future specialists, formation of their mathematical and ICT competencies.

The content of DE training was supplemented by professionally oriented models of real problem situations and systematized tasks for students' classroom and independent educational activities. The systematization and structuring of the five types of tasks by the levels of difficulty contributed to the transformation of the external educational goals of the students into the internal during the study.

The implementation of professionally oriented task-cases during DE studies helped simulate students' future professional activities. The organization of the educational activity and its management was carried out through the site http://difur.in.ua/, consisting of four content modules. The training module provides theoretical and practical training of DE and access to information materials. The methodological module contains the syllabus of the discipline and methodological recommendations for its study. The cognitive module supports the connection between the teacher and the student, allowing access to software and cloud technologies. The monitoring module helps to control the effectiveness of the training (Fig. 1).

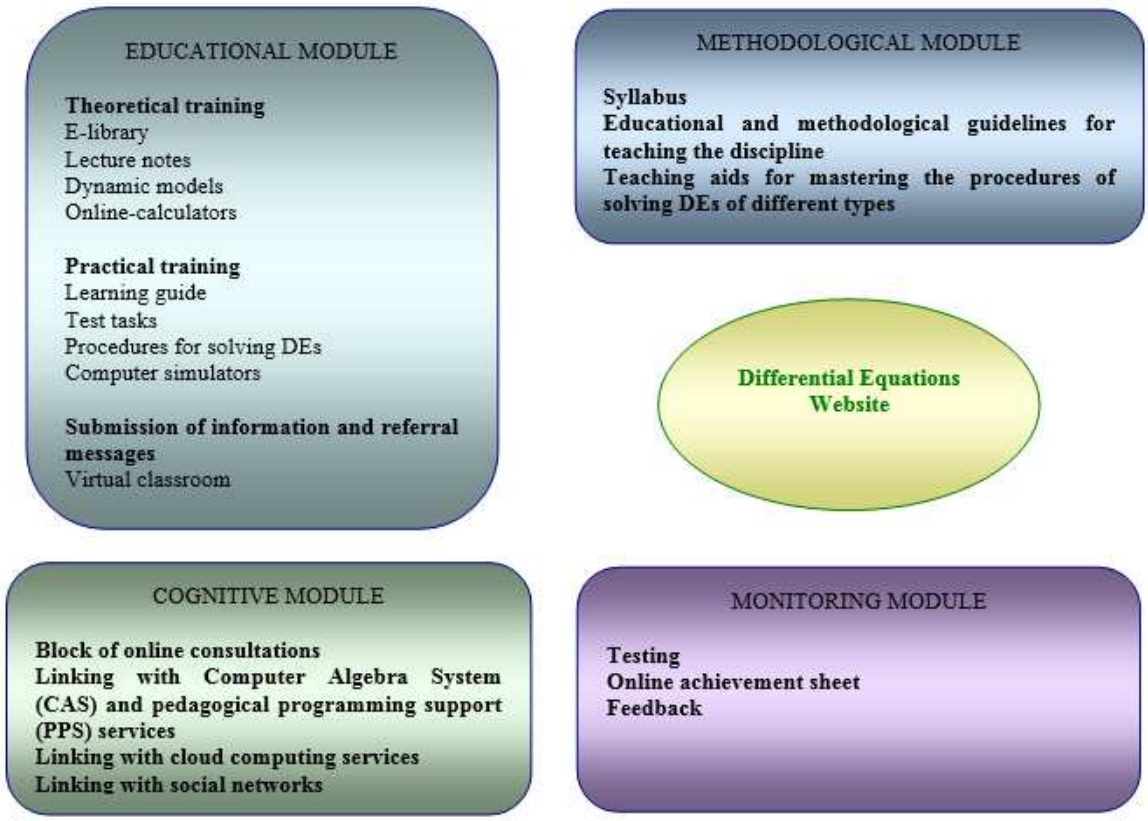

Fig. 1. "Differential Equations" site structure

The use of computer-oriented technology of education helped to organize students' independent educational activities, contributed to the transition of students to research

methods of mastering the discipline. On top of that, the use of computer technology has made it possible to update the methods of educational activity, in particular, the methods of knowledge actualization, the control of the educational and cognitive activity, the methods of consolidating and applying the learned educational material. The educational and cognitive modules of the training site contributed to the teacher's cooperation with students and students with each other during classroom and independent learning activities. These modules created the conditions for transitions from the frontal work to the group and individual forms of learning activity through the use of local devices for presentation of the training material.

Computer-oriented support of the educational process was aimed at assisting the teacher in the use of partial-search or research teaching methods. This approach has contributed to the rational use of study time in analyzing various approaches to creating differential models and solving them.

Indicators of the estimation of the effectiveness of implementing the developed technique in the process of studying DEs by students were: levels of mastering certain initial skills by students (applying procedures for solving various types of differential equations of the first order, higher orders and systems of differential equations), levels of forming students' skills in mathematical modelling and abilities, which are necessary for the future professional activity of IT specialists, in particular the development of their ICT competencies.

We chose criteria for the analysis of students' achievements in mastering DEs on the grounds that educational and professional activities of IT bachelors should be aimed at developing their educational skills that involve the use of procedures for solving DEs and their systems. In this process, positive dynamics of redistribution of students from the initial level to sufficient and creative was observed. Training students' skills in mathematical modelling should facilitate their transition from the initial to the normative level, and the development of students' ICT competencies allows to increase levels from very low and initial to normal, high and very high.

After finishing studying the discipline (at the end of the third or fourth semester, depending on the curriculum) final tests were conducted, which gave an opportunity to determine the level of formation of the investigated skills in the experimental and control groups. Tasks of the final control were posted on the site. Students were asked to solve the tasks, which allowed determining the final level of skills formation: the use of procedures for solving DEs and their systems, mathematical modelling, activation of skills necessary for future professional work of IT specialists.

Students were able to keep track of the results of their assessment with the help of online record books located in the virtual room of the site.

The analysis of the results of the experiment formation stage confirmed that the teaching of differential equations according to our method contributes to the optimal interaction of the teacher and the student. The implantation of the methodology in the learning process had an impact on the formation of the students' ability to use the procedures for solving DE, the development of mathematical modeling skills, the formation of students' ICT competencies.

3. RESULTS

The development and experimental implementation of the developed methodology took place during the preliminary, search and forming stages. The analysis of the results of the preliminary stage of the experiment showed low levels of students' ability to apply certain procedures for solving DE, skills in mathematical modeling. 61% of the students showed very low and beginner levels of ICT Competencies.

The search stage of the pedagogical experiment made it possible to develop and correct the computer-oriented methodology and to create a computer-oriented accompaniment of DE

classroom teaching and students' independent work. During the preparation for the classes and consultations, the teacher had the opportunity to plan the involvement of computer-based learning tools that comprise the content of the developed training site. Under this approach, the teacher had the opportunity to take into account the individual characteristics of students. What is more, forming their ICT competencies, the teacher was able to provide educational and professional activities while studying DE research character, promote the quality of students' training through the use of a professional language and tools that accompany the work of future IT professionals.

The effectiveness of the implementation of the computer-oriented methodology for DE students was confirmed during the formative stage of the experiment.

Upon completion of the study of the discipline (at the end of the third or fourth semester, depending on the curriculum), the final control test was conducted, which allowed determining the level of formation of the investigated skills in the experimental (EG) and control groups (CG). The task of the final control test was posted on the site. Students were asked to solve tasks which allowed determining the final level of the formation of skills: the use of procedures for solving DE and their systems, mathematical modeling. The generalized results of this work are presented in table 1.

Table 1

Results of solving tasks of the final control test, distribution of students by levels of skills formation

Groups	Levels									
	The use of procedures for solving DE						Mathematical modeling			
	Beginner		Sufficient		High		Beginner		Normative	
EG n_1=219	Q_{11}=104	47,5%	Q_{12}=100	45,7%	Q_{13}=15	6,8%	Q_{11}=141	64,4%	Q_{12}=78	35,6%
CG n_2=213	Q_{21}=127	59,6%	Q_{22}=74	34,7%	Q_{23}=12	5,6%	Q_{21}=161	75,6%	Q_{22}=52	24,4%

The empirical value of the T criterion χ^2 was calculated, which made it possible to analyze the levels of student application of procedures for solving DE and their systems:

$$T = 219 \cdot 213 \cdot \left[\left(\frac{104}{219} - \frac{127}{213} \right)^2 \div (104+127) + \left(\frac{100}{219} - \frac{74}{213} \right)^2 \div (100+74) + \left(\frac{15}{219} - \frac{12}{213} \right)^2 \div (15+12) \right] =$$

$$= 6{,}426.$$

For the level of significance 0,05 and $L-1=2$ critical value $\chi^2_{0,05} = 5{,}99$, so $T > \chi^2_{0,05}$.

Also, the empirical value T was calculated to analyze the formation of students' mathematical modeling skills:

$$T = \frac{432 \cdot (141 \cdot 52 - 78 \cdot 161)^2}{219 \cdot 213 \cdot (141+160) \cdot (78+53)} = 6{,}442.$$

For the level of significance 0,05 and $L-1=1$ critical value $\chi^2_{0,05} = 3{,}84$, so $T > \chi^2_{0,05}$.

In addition, it was confirmed that the level of development of ICT competence of future specialists in the experimental group as compared with the control group also had statistically significant differences.

The final testing of the students in the control and experimental groups in order to check their redistribution by the levels of ICT competencies formation was carried out on the basis of an analysis of the students' use of ICT during the performance of the tasks of the final control test. The evaluation results are presented in table 2.

Table 2

Results of the incoming testing of students' ICT competencies

Groups	Levels									
	Very low		Beginner		Normative		High		Very high	
EG n_1=219	Q_{11}=11	5%	Q_{12}=85	38,8%	Q_{13}=80	36,5%	Q_{14}=28	12,8%	Q_{15}=15	6,8%
CG n_2=213	Q_{21}=14	6,6%	Q_{22}=111	52,1%	Q_{23}=60	28,2%	Q_{24}=15	7%	Q_{25}=13	6,1%

Confirmation of an increase in the level of formation of ICT competencies was provided by calculation:

$$T = 219 \cdot 213 \cdot \left[\left(\frac{11}{219} - \frac{14}{213} \right)^2 \div (11+14) + \left(\frac{85}{219} - \frac{111}{213} \right)^2 \div (85+111) + \left(\frac{80}{219} - \frac{60}{213} \right)^2 \div (80+60) + \right.$$

$$\left. + \left(\frac{28}{219} - \frac{15}{213} \right)^2 \div (28+15) + \left(\frac{15}{219} - \frac{13}{213} \right)^2 \div (15+13) \right] = 10{,}658.$$

For the level of significance 0,05 and $L-1=4$ critical value $\chi^2_{0,05} = 9{,}49$, so $T > \chi^2_{0,05}$.

According to the analysis of the results of applying the computer-oriented methodology of training in DEs, there was a significant improvement of the students' indices in the experimental group in comparison with the corresponding indicators of the students in the control group (Fig. 2).

Thus, when carrying out the experiment we observed positive dynamics of changes in students' average grades in the experimental group. The average level of the use of procedures for solving DEs of different types and their systems increased by 1.71 points, the level of the skills of mathematical modeling improved by 0.56 points, the level of ICT competencies increased by 1.77 points. Differences are statistically reliable with the probability of 99%.

In addition, we tested the effect the computer-oriented methods of practical training of DE have on the organization of the Bachelor students' educational and professional activity, the effectiveness of which was indicated by the positive dynamics of the values of the following parameters.

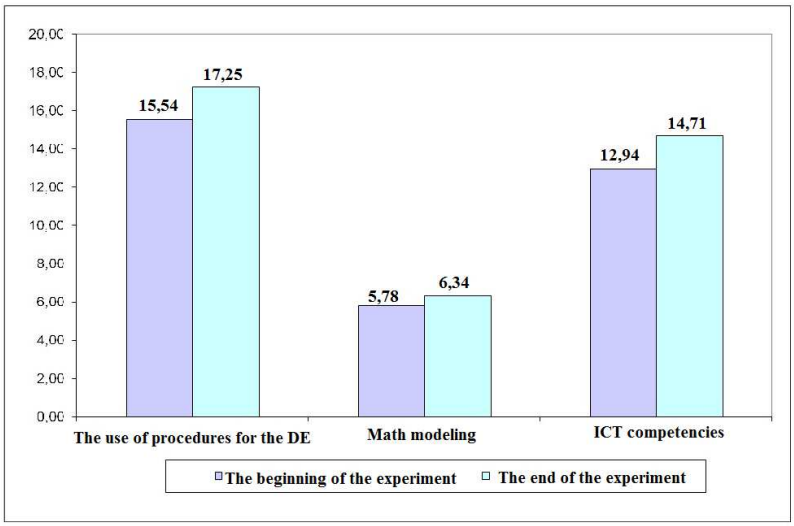

Fig. 2. Dynamics of changes in average grades of EG students during the experiment

The obtained results confirmed the hypothesis that the introduction of the developed technique positively affects mastering differential equations by students.

4. DISCUSSION

Let us consider the components of the developed methods. One of the peculiarities of content presentation of the discipline «Differential Equations», as well as of any other mathematical discipline, is stable interdependence and continuity in the presentation of learning material. For example, some equations of the second order are reduced to the first-order equations by means of a certain substitution, and most of the first-order differential equations, in turn, can be reduced to the equations with separable variables through certain transformations. Thus, when mastering solutions of DEs, students must constantly refer to the previously acquired knowledge and skills. Taking into consideration a small amount of time given for discipline studying and a significant amount of training material, it is very important to get an idea of the overall structure of the course and learn to quickly navigate through training materials for effective mastering of DEs. For this purpose, educational material offered to students should be clearly structured, and theoretical information and examples of problem-solving are grouped according to certain types and attributes. This goal can be achieved through computer-based technologies, such as systematized technologies for maintaining the process of transferring knowledge and skills to students and their mastering when learning DEs.

The ability to solve differential models is formed by applying appropriate procedures for solving equations of different types. It is important to repeatedly implement each procedure in order to form the student's appropriate actions. We believe that computer-based technologies can accompany the process of solving training problems, taking into account the differentiation of education and students' individual capabilities. This conclusion agrees with the recommendations [11, 14] indicating the relevance of applying these technologies for accounting students' individual characteristics and their abilities to master training material: each of the students requires a different amount of time to learn a particular educational material; each of the students may him/herself choose time to master the discipline (asynchronous training mode). Providing both synchronous and asynchronous modes of learning, the technologies under research can also help the teacher to organize students' educational and professional activities while solving systematized tasks which assist in mastering the research object model adequacy analysis, procedures for solving informatization objects and processes modelling tasks, optimization forecasting, optimal control and decision-making problems; developing concepts for computer implementation of research object models, studying models controllability.

Quick access to systematized tasks and means which have to accompany the organization of their solution can be provided through the development of a training site. We believe that adding educational sites to tutorials provides the basis for the formation of an educational information environment in higher education, which contributes to the improvement of educational outcomes, ensures the coordination of students' learning activities, organization of blended learning and management of learning and professional activities of future specialists, development of their ICT competencies.

Such information environment is created by the wide use of Web 2.0 technology services, blended (classroom, remote, and mobile) learning technologies, cloud technologies which affect the interconnection of all components of the methods. This dependence is based on the combination of didactic principles of traditional and distance learning, provided with the use of computer-based learning tools to ensure:

- combination of students' collective educational activity with the individual approach to students' learning of DEs;
- stimulation and motivation of students' educational and professional activities;
- educational materials that satisfy the students' needs at any time;
- the desirability of activating computer-oriented training facilities at all stages of the formation of future specialists' actions;
- formation of abstract and systemic thinking of future specialists through the correlation of visual component, auditory perception and interactivity.

In addition, the interactivity of the process of forming cognitive activities in the process of practical teaching of DE to students can be provided by using the educational book «Computer-Oriented Practical Classes on Differential Equations» [13]. We developed 16 practical classes based on the combination of traditional and computer methods and forms of learning and knowledge control and focused on solving problems that ensure continuity between practical classes and lectures on the basis of internal and interdisciplinary logical connections which are important for future professionals.

The educational book contains methodological recommendations for organizing practical classes and offers educational materials, which are:

- intended for use in order to master procedures of solving various types of differential equations of the first order, linear differential equations of the n-th order and systems of differential equations;
- presented with regard for different attainment levels of students actively involved in the independent activity with their own choice of the available level of knowledge acquisition;
- intended through their structure to create presentations that can be used when teaching students to solve differential equations and mathematical modeling;
- intended for an acquaintance of students with computer technologies and development of ICT competencies;
- represented by a system of tasks (mathematical, practical, professionally focused) that promote the conscious application of knowledge and skills to use differential models in students' future professional activities, in determining actions and operations to be performed in the process of mathematical modeling;
- designed to test students' acquired knowledge and skills.

For the organization of practical classes, the following tasks are used in the manual:

- tests that allow managing oral interviewing of students;
- pedagogical software tools designed for graphical analysis of the integral curves that can be obtained when solving differential equations and their systems;
- online calculators designed for checking resolutions of differential models in the process of forming students' mathematical modeling skills;
- dynamic models, which through animation and semi-automatic control help the teacher visualize models of social, economic, physical and other processes;
- simulators that can be used by the teacher to accompany the examination of the results achieved by the students, revision, and mastering of training materials, promote the formation and improvement of practical skills of future specialists.

All the above-mentioned materials and facilities are posted on the educational website. Mastering of training materials by students with the help of a teaching manual may be accompanied by the use of site materials.

5. CONCLUSIONS AND PROSPECTS OF FURTHER RESEARCH

As it has been experimentally proved, the development and implementation of computer methodology contributed to the effectiveness of the process of students' mastering differential equations. The organization of educational and professional activities and their management was carried out through the training site. The concept of the implementation of the site provided the student connection with a teacher in synchronous and asynchronous modes, services of online calculators, systems of computer mathematics, a software of data visualization and results of tasks solving.

The developed tools of computer-oriented technique give the teacher the opportunity to combine traditional and innovative methods and forms of learning, facilitating the transition to more active ones and making them computer-oriented. The use of the site helped to activate all types of students' sensory perception. Furthermore, the openness of the training exercises system and the individualization of the educational process allowed the teachers to apply both traditional and computed-oriented methods of training organization in practical classes.

Thus, the suggested approach contributed to the implementation of modernized teaching methods, in particular, methods for updating knowledge, controlling educational and cognitive activity, methods of consolidation and application of the studied educational material. Likewise, the components of the training site provided cooperation between teacher and students, on the one hand, and among the students, on the other hand, both in class and during their independent study.

At the next stage of the research, we plan to determine the methodology for training teachers in the creation and use of ICT tools for teaching mathematical disciplines.

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МЕТОДИКА КОМП'ЮТЕРНО ОРІЄНТОВАНОГО НАВЧАННЯ ДИФЕРЕНЦІАЛЬНИХ РІВНЯНЬ СТУДЕНТІВ ЗАКЛАДІВ ВИЩОЇ ТЕХНІЧНОЇ ОСВІТИ

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Анотація. Обґрунтовується, що ефективність навчання студентів диференціальних рівнянь може бути досягнута шляхом розробки і впровадження комп'ютерно орієнтованої методики в процес навчання. Цілі навчання диференціальних рівнянь бакалаврів скориговані таким чином, щоб забезпечувати результати, що полягають у сформованості вмінь студентів застосовувати процедури розв'язування різних типів диференціальних рівнянь і їх систем, моделювати певні процеси за допомогою диференціальних рівнянь, використовувати програмні засоби під час розв'язування задач на дослідження властивостей математичних моделей. Зміст навчання доповнено систематизованими завданнями і професійно орієнтованими моделями реальних проблемних ситуацій, згрупованими за рівнями складності.

Розроблені та описані засоби комп'ютерно орієнтованих технологій навчання допомагають викладачеві комбінувати традиційні і активні методи і форми навчання, сприяючи здійсненню переходів до більш активних із них і роблячи їх комп'ютерно орієнтованими. Контент створеного сайту «Диференційні рівняння» (режим доступу: http://difur.in.ua/) і розроблена концепція його використання забезпечують викладання дисципліни. Експериментальна перевірка ефективності розроблених елементів комп'ютерно

орієнтованої методики навчання диференціальних рівнянь підтвердила висновки про результативність її впровадження в навчальний процес вищої технічної школи.

Ключові слова: диференціальні рівняння; комп'ютерно орієнтоване навчання; вища технічна школа; математичне моделювання.

МЕТОДИКА КОМПЬЮТЕРНО ОРИЕНТИРОВАННОГО ОБУЧЕНИЯ СТУДЕНТОВ ВЫСШЕЙ ТЕХНИЧЕСКОЙ ШКОЛЫ ДИФЕРЕНЦИАЛЬНЫМ УРАВНЕНИЯМ

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Аннотация. В статье обосновывается, что эффективность обучения студентов дифференциальным уравнениям может быть достигнута путем разработки и внедрения компьютерно-ориентированной методики в процесс обучения. Цели обучения дифференциальным уравнениям студентов скорректированы таким образом, чтобы обеспечивать результаты, которые заключаются в сформированности умений будущих бакалавров применять процедуры решения различных типов дифференциальных уравнений и их систем, моделировать определенные процессы с помощью дифференциальных уравнений, использовать программные средства при решении задач на исследование свойств математических моделей. Содержание обучения дополнено систематизированными задачами и профессионально ориентированными моделями реальных проблемных ситуаций, сгруппированными в зависимости от уровня сложности.

Разработанные и представленные средства компьютерно ориентированных технологий обучения помогают преподавателю комбинировать традиционные и активные методы и формы обучения, способствуя осуществлению переходов к более активным из них и делая их компьютерно ориентированными. Контент созданного сайта «Диференційні рівняння» (режим доступа: http://difur.in.ua/) и разработанная концепция его использования обеспечивают преподавание дисциплины. Экспериментальная проверка эффективности разработанных элементов компьютерно ориентированной методики обучения дифференциальных уравнений подтвердила выводы о результативности ее внедрения в учебный процесс высшей технической школы.

Ключевые слова: дифференциальные уравнения; компьютерно ориентированное обучение; высшее техническое заведение; математическое моделирование.