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Information and Communication Technologies of Teaching Higher Mathematics To Students of Engineering Specialties At Technical Universities

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Abstract

Excessive anthropogenic pressure on land resources in Ukraine leads to a deterioration of their quality, and consequently they lose their potential. Human impact on the change of land quality can be direct (by involving land lots in use, carrying out economic activities) and indirect (as a result of such activity, enhancing the natural degradation of soils). The tendency of deterioration of the state of land resources requires the subordination of land relations to the main goal – to ensure comprehensive protection of this major national wealth of Ukraine.

Legal support for the protection of agricultural land is considered as a single complex of interdependent elements: legal standards for the protection of land, soil, agricultural landscapes, and the mechanism for their implementation – legally significant measures: economic, organizational, scientific and technical. At the same time, it was concluded that the system of legal regulation of the use of agricultural land is not sufficiently saturated with mechanisms for regulating agricultural activity.

Keywords: Ukraine, land protection, agricultural lands, soil, land plots, agriculture.

Аннотация

Высшие технические учебные заведения развитых стран имеют значительные педагогические достижения и развитую систему подготовки специалистов инженерных направлений на основе системного использования средств ИКТ. В глобализованном пространстве высшего образования проблему повышения качества подготовки специалистов в отечественных вузах целесообразно решать посредством творческого использования опыта передовых вузов инженерного профиля.

Цель исследования заключается в осуществлении анализа процесса развития информационно-коммуникационных технологий (ИКТ) обучения высшей математике студентов инженерных специальностей технических вузов.

В статье отмечена актуальность фундаментальной математической подготовки будущих специалистов технического профиля. На основании экспертного опроса проведен анализ инструментов ИКТ для совместной работы над проектами при изучении высшей математики, дана характеристика систем компьютерной математики (СКМ) и Web-СКМ и определены методы, формы и средства обучения в соответствии с разделами высшей математики, которые изучаются студентами инженерных специальностей в технических вузах.

Ключевые слова: информационно-коммуникационные технологии, высшее учебное заведение, студенты инженерных специальностей, система компьютерной математики, мобильные математические среды, онлайн-консультация.

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Introduction

At the present stage of the development of the information society, the use of information and communication technology (ICT) tools contributes to the globalization of education, development of the international labor market, and growth of various types of an individual's mobility (Ushatikova et al., 2018). The growth of academic mobility, as well as the introduction of international norms and standards, based on which academic qualifications from different countries can be compared and recognized, lead to increased competition between universities and improve the quality of higher education (Zhienbayeva et al., 2019; Zholdasbekov et al., 2019). In this context, the globalization of education contributes to the personal and professional development of specialists who are involved in the development and introduction of new technologies – engineers (Bulgarova et al., 2018; Sergeeva et al., 2018).

One of the components of a professional engineer's training system is fundamental training, the main task of which is to improve the professional training and all-around development of a student as a person. This includes: mastering research methods for solving production tasks; development of rationalization suggestions and participation in inventive work; knowledge of technology and equipment from the field of one's specialization (specialty) and mastering various forms of self-education, which is impossible without fundamental knowledge of higher mathematics, and skills to put the acquired knowledge into practice and apply it in professional activity.

The use of ICT in the process of teaching higher mathematics to students of engineering specialties creates the conditions for student's self-realization. They help to increase their learning activity, develop critical thinking, form students' skills in organizing independent work, develop creative abilities and leadership qualities, increase responsibility for the results of their work, as well as improve the learning process and its quality.

Therefore, there is a need to study the possibilities of using ICT tools for teaching higher mathematics to students of engineering specialties at technical universities.

Literature review

The analysis of scientific literature showed that the problems of the development of the theory

and methods of using ICT in education are traditionally in the purview of Russian and foreign scientists.

Researchers (Martens et al., 2011) determine the following characteristics of teaching technology: 1) teaching is an observable process and its results are measurable; 2) the process of achieving the desired teaching results is defined in terms of clearly defined operations; 3) these operations are defined on the basis of evidence. It is noted that computer-oriented teaching technologies most fully implement these characteristics, because 1) monitoring of the teaching process is mediated and its results are recorded, processed, and generalized using ICT tools, 2) the teaching process is algorithmized and implemented in a computer program, and 3) actions that manage the teaching process are selected in accordance with the teaching results. Thus, the choice of ICT tools for the implementation of teaching technology is appropriate.

The theory and methods of using ICT in teaching higher mathematics were developed in the works of such Russian researchers as V.A. Krasilnikov (2012), V.P. Diakonov (2010), V.F. Ochkov (2013), L.V. Sardak (2016), and others.

E.S. Polat (2010) defines ICT as a set of methods, means, and techniques used to collect, organize, store, process, transmit, and present various messages and data. I.N. Semenova and A.A. Slepukhin (2013) define ICT as information technologies based on personal computers, computer networks, and communications, which are characterized by a user-friendly environment. According to C. Blurton (1999), ICT are different technological tools and resources that are used for communication and for the creation, distribution, storage, and management of data. According to researchers, the use of ICT-teaching supports traditional education and helps people cope with learning throughout their lives because it makes the learning process easy, motivated, individual, and flexible (Leach, 2005).

Among works of foreign scientists, the following works are important for the research:

- Birch (2009), R.M. Hernandez (2017), G. Douglas (2001), N. Selwyn (2007) (the works are devoted to the history and current state of the use of ICT in the teaching process);

- M. Goyal (2009), M. Sandi (2009), E.R. Krueger (2010) (the works are devoted to the use of ICT in the training of students of engineering specialties);
- L. Bazzini (2003), R. Wood (2008), P. Drijvers (2010) (the works are devoted to the use of ICT in the process of studying mathematical disciplines).

J. Engelbrecht and A. Harding (2005) note that Internet education in mathematics is developing as a new teaching method with its own characteristics and capabilities that differ from traditional teaching methods.

The research hypothesis: The emergence of new ICT leads to changes in the theory and methods of teaching higher mathematics, which leads to the emergence of new goals, means, forms, and methods of organizing the teaching process.

Proposed Methodology

General description

The specificity and purpose of the work determine the choice of a set of scientific research methods:

- analysis of scientific and pedagogical, as well as methodological literature in the field of education, in order to reveal the state of implementation of ICT tools

in the educational practice of technical universities;

- analysis, synthesis, and theoretical generalization of experience in the use of ICT in the process of teaching higher mathematics;
- expert survey of teachers in order to reveal tools, methods, forms, and means of teaching mathematical disciplines that are used with the help of ICT at technical universities.

Thirty-five experts, teachers and employees of the departments of higher and applied mathematics of Russian technical universities took part in the discussion and comparison, as well as in the expert survey.

Algorithm

At the first stage of the study, an analysis of scientific literature on the problem of using ICT for teaching higher mathematics to students of engineering specialties at technical universities was conducted.

At the second stage of the study, methods, forms, and means of teaching mathematical disciplines using ICT at technical universities were determined.

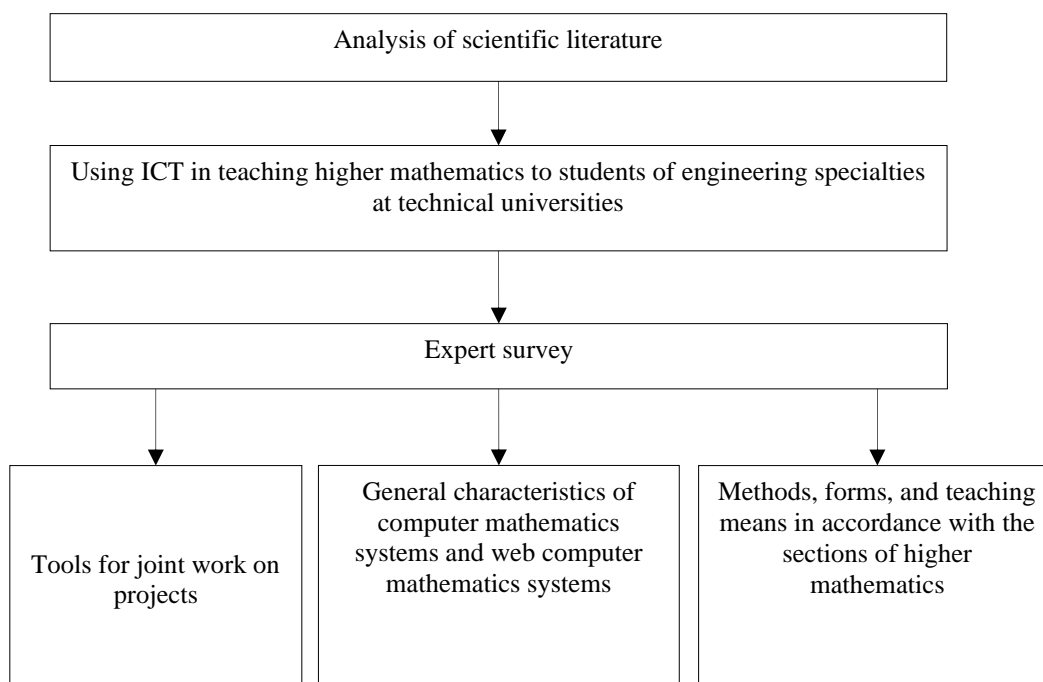


Figure 1. Flow chart of methodology

Results and discussion

An expert survey showed that a large number of various means of supporting mathematical educational activities have been developed and implemented in the teaching process now, among which are the following:

- tools for joint work on projects;
- means for supporting domain-specific practice.

Using tools for joint work on projects, teachers can support the learning process at a distance, outside the auditorium (Table 1).

Table 1. Tools for joint work on projects

№	Tool	Capabilities	% of mentions
1	Google GoogleDocs	creating various documents, working with them together with students and saving documents and other files online, providing access to these documents to others; the ability to access one's documents and files from any computer, if it is connected to the Internet.	91,4%
2	Microsoft Office Web Apps	viewing and sharing files regardless of user's location; the ability to work simultaneously with other people on documents on different platforms, devices and in different versions of Office; saving documents online for sharing.	85,7%
3	Cloud data storage DropBox	the ability to store data on cloud-based servers and share it with other users on the Internet. The work is based on data synchronization.	85,7%
4	Platforms for online teaching and web conferences: Elluminate, iLinc, WiZiQ	Using these resources, one can organize webinars (web conferences) online or record them. Published courses in any format in a library can be shared in a virtual classroom or distributed to students. The most often used file types are available for download: PDF, Word, PowerPoint, Excel, video and audio files. One has access to the board and download training materials before or during class. Uploaded files are hosted in the cloud.	80%
	platforms Piazza, Skype, Google+	support of interactive extracurricular interaction between teachers and students.	77,1%

Computer support for subject-oriented practical activity consists in providing the user (student or teacher) with a set of means and tools that automate and allow seeing the process of solving a practical problem. Such a system should be provided with a full set of methodological support. For higher mathematics, there is a textbook, problem book, reference book, student workbook, collection of tests, methodological recommendations of the teacher, etc.

When conducting complex calculations of an intermediate nature, the solution of which takes a large amount of time, according to the experts, it is advisable to use computer mathematics systems (CMS). At the same time, the existence of a large number of available mathematical

packages (MATLAB, Mathematica, Mathcad, Maple, Statistica, etc.) allows the teacher to choose a convenient, accessible, and understandable resource for them, taking into account the indicated advantages and disadvantages of this software.

According to the analysis of the educational practice of technical universities in the USA and the expert survey, the most popular CMS used in teaching higher mathematics in the USA are Mathematica, MATLAB, Maple, GAUSS, Scilab, Mathcad, Maxima, and Sage.

In Table 2, the general characteristic of some CMS used in US universities in teaching higher mathematics is presented.

Table 2. General characteristic of CMS used in teaching higher mathematics in the US

Name	Developer	General characteristics	
		advantages	disadvantages
MATLAB R2013b	The MathWorks	<ul style="list-style-type: none"> - universal CMS for fast and accurate numerical calculations in various subject areas; - openness and scalability; - support of 3D graphics; - compatibility with various operating platforms; - supports work with databases. - built-in support of parallel computing; - statistical analysis of models; - uniqueness of 3D-graphics; - compatibility with various operating platforms; 	<ul style="list-style-type: none"> - lack of support for solving inequalities and recurrence relations in the core; - exactingness to the hardware resources of the information system.
Mathematica 9.0.1	Wolfram Research	<ul style="list-style-type: none"> - high speed of performing mathematical operations and calculations; - has a developed graphical interface, which makes it possible to work with many documents; - supports work with databases. - best symbolic core; - high accuracy of calculations; - introduction of mathematical expressions in natural mathematical notation; - structured document; - intuitive interface; - has a developed graphical interface, which makes it possible to work with many documents; - in the latest versions there is a panel for recognizing characters entered by hand, for quick search of a desired command or character; - interaction with CAD. - free; - plenary power for statistical analyzes, including linear and non-linear regression, - classical statistical tests, analysis of time series, cluster analysis, etc.; - can be used for matrix calculations; - the ability to connect the code written in C, C ++ or Fortran; 	<ul style="list-style-type: none"> - syntax complexity; - the idea of data as a combination of individual expressions, which reduces the performance of solving complex problems.
Maple 17	Waterloo Maple Inc.	<ul style="list-style-type: none"> - contains tools for visualizing the results of calculations (2-dimensional, 3-dimensional graphs, charts, histograms, Gantt charts (schemes), etc.); - Sweave function that allows to create dynamic reports; - users can expand the functionality by writing new functions; - provides the ability to create high-quality graphics with various attributes, including mathematical formulas and symbols. - provides an opportunity to solve problems in algebra, numbers theory, geometry and combinatorics; - works on Unix-like and Linux operating systems, and also Windows; - has a developed graphical interface that provides the ability to work with many documents; - supports work with databases. 	<ul style="list-style-type: none"> - inconvenience when working with a large amount of numerical data; - the idea of data as a combination of individual expressions, which reduces the performance of solving complex problems.
R 3.0.2	Ross Ihaka, Robert Gentleman	<ul style="list-style-type: none"> - contains tools for visualizing the results of calculations (2-dimensional, 3-dimensional graphs, charts, histograms, Gantt charts (schemes), etc.); - Sweave function that allows to create dynamic reports; - users can expand the functionality by writing new functions; - provides the ability to create high-quality graphics with various attributes, including mathematical formulas and symbols. - provides an opportunity to solve problems in algebra, numbers theory, geometry and combinatorics; - works on Unix-like and Linux operating systems, and also Windows; - has a developed graphical interface that provides the ability to work with many documents; - supports work with databases. 	<ul style="list-style-type: none"> - command interpreter is used for work.
MAGMA V2.19-10	Computational Algebra Group, School of Mathematics and Statistics, University of Sydney	<ul style="list-style-type: none"> - contains tools for visualizing the results of calculations (2-dimensional, 3-dimensional graphs, charts, histograms, Gantt charts (schemes), etc.); - Sweave function that allows to create dynamic reports; - users can expand the functionality by writing new functions; - provides the ability to create high-quality graphics with various attributes, including mathematical formulas and symbols. - provides an opportunity to solve problems in algebra, numbers theory, geometry and combinatorics; - works on Unix-like and Linux operating systems, and also Windows; - has a developed graphical interface that provides the ability to work with many documents; - supports work with databases. 	<ul style="list-style-type: none"> - lack of support for integration, solving inequalities, differential equations, recurrence relations in the core.

According to the experts, mobile mathematical environments are a new promising direction for the development of CMS. At the same time, CMS is integrated into one single network environment, i.e. transfer of application software (even “desktops”) to the web environment. It is important that the use of mobile web environments in the educational process allows

integrating classroom and extracurricular work in a continuous educational process.

The experts point to the following abilities of web CMS:

- 1) performance of any calculations, both analytical (actions with algebraic expressions, solving equations, differentiation, integration) and numerical (exact – with any digit capacity, approximate – with any predetermined accuracy);

- 2) presentation of the calculation results in a form convenient for perception and construction of two- and three-dimensional graphs of curves and surfaces, histograms and any other images (including animated ones);
- 3) combination of calculations, text, and graphics on worksheets with the possibility of printing, publishing on the network and joint work with them;
- 4) creation using built-in programming languages of models for the implementation of educational research.

The main areas of application of web CMS in the process of teaching higher mathematics, according to the experts, include graphical interpretation of mathematical models and theoretical concepts, automation of routine computing, support of independent work, and organization of mathematical research (Table 3).

Table 3. General characteristic of web CMS

Nº	Web CMS	Characteristic	% of mentions
1	Sage	mobile mathematical environment that acts as an integrator of various mathematical packages with a joint Web interface.	85,7%
2	Wolfram Demonstrations Project	contains a large number of demonstrations in higher mathematics and has an open access code. In demonstrations, one can provide different measures to parameters and conduct object research An easy to use applet can be used directly in a Web browser or downloaded to a computer. Users are provided with empty two-dimensional planes on which they can make constructions and perform manipulations with. In an open field, users can set equations. It is a universal tool for studying a wide range of topics of two-dimensional plane geometry. During higher mathematics classes it is convenient to illustrate the basic mathematical concepts and constructions and calculate.	74,3%
3	GeoGebra	contains a large number of demonstrations in higher mathematics and has an open access code. In demonstrations, one can provide different measures to parameters and conduct object research An easy to use applet can be used directly in a Web browser or downloaded to a computer. Users are provided with empty two-dimensional planes on which they can make constructions and perform manipulations with. In an open field, users can set equations. It is a universal tool for studying a wide range of topics of two-dimensional plane geometry. During higher mathematics classes it is convenient to illustrate the basic mathematical concepts and constructions and calculate.	71,4%

Based on the analysis of the expert survey and expert suggestions, the methods, forms, and teaching means were regulated in accordance with the sections of higher mathematics that are

studied by students of engineering specialties at technical universities (Table 4).

Table 4. Methods, forms, and teaching means were regulated in accordance with the sections of higher mathematics that are studied by students of engineering specialties at technical universities

№	Sections	Forms	Methods	Means
1.	Linear algebra	Lecture; computer-oriented practical lessons; implementation of individual tasks; online consultations	Problem method	Sage, MathCad
2.	Vector algebra	Lecture; practical lesson; implementation of individual tasks; control activity; online consultations	Information-receptive method. Graphic work	GeoGebra, Wolfram Demonstrations Project
3.	Analytic geometry	Lecture; computer-oriented practical lessons; independent work of students; computer control of the quality of knowledge; online consultations	Information-receptive method. Demonstration (dynamic)	Smath Studio, Maple,
4.	Boundary conditions	Lecture; practical lesson; implementation of individual tasks; online consultations	Partially searching method (heuristic)	Maple, MathCad, FooPlot
5.	Differential calculus of a one-variable function	Lecture; computer-oriented practical lessons; independent work of students; online consultations	Information-receptive method. Demonstration (dynamic)	Maple, Wolfram Demonstrations Project, FooPlot
6.	Indefinite and definite integrals	Lecture; practical lesson; implementation of individual tasks; computer control of the quality of knowledge; online consultations	Searching method (experimental)	Sage, MathCad
7.	Functions of several variables	Lecture; computer-oriented practical lessons; control activity; independent work of students; online consultations	Information-receptive method Demonstration (dynamic)	Maple, GeoGebra
8.	Differential equations	Lecture; computer-oriented practical lessons; independent work of students; control activity; online consultations	Searching method (experimental)	Smath Studio, MathCad
9.	Multiple integrals	Lecture; computer-oriented practical lessons; control activity; independent work of students; online consultations	Problem method	MathCad
10.	Series	Lecture; practical lesson; implementation of individual tasks; computer control of the quality of knowledge; online consultations	Information-receptive method	MathCad
11.	Probability theory	Lecture; practical lesson; control activity; independent work of students; online consultations	Problem method	MathCad
12.	Fundamentals of mathematical statistics	Lecture; computer-oriented practical lessons; practical training; control activity; online consultations	Partially searching method (heuristic)	Statistica

According to the experts, the introduction of new teaching means inevitably leads to a change in teaching methods and forms. With the emergence and introduction of ICT tools in the process of

teaching higher mathematics, a combination of traditional forms of teaching with computer-oriented (based on the systematic, consistent, and logical use of ICT in the teaching process) occurs.

As the interviewed experts indicate, in the new model of combined teaching, the educational process of higher mathematics contains the main traditional forms of organization of the educational process: lecture, practical lesson, independent work of students, and knowledge control. In addition, traditional forms are supplemented by forms of organizing distance and mobile learning, as well as learning using the Internet and multimedia: course materials, online communication, individual and group online projects, virtual classroom, audio and video lectures, animation and simulation, mobile training, etc.

At a lecture, the teacher presents the main educational material of the course. The explanations, which are accompanied by lecture demonstrations using software tools, contribute to a better understanding and assimilation of the concepts in question. Recorded lectures posted on the Internet allow students to refine unclear material. If it is impossible for a teacher to be present at the lecture or submit the material to an independent study, it is advisable, according to the experts, to replace the traditional lecture with a web conference (webinar, video lecture) and multimedia lectures.

During a practical lesson, students solidify their knowledge and acquire skills in solving practical problems. The tasks of a practical lesson should be selected according to the direction of student training, emphasizing the appropriateness of the studied material in students' future professional activity. According to the experts, it is advisable to post questions and tasks of a practical lesson and examples for independent work on the Internet in advance.

In addition, according to the experts, it is advisable to use ICT tools for rapid testing to determine the level of learned material during a practical lesson. At the same time, for self-control, students should be provided with clear instructions for working with CMS, which will allow them to check answers and to form CMS skills for their future professional activity.

The experts specify that when using CMS in the process of teaching higher mathematics one should consider the following:

- provide students with information about various available mathematical packages and methodological materials for their use, allowing students to independently choose a product convenient for them;

- offer students tasks that should be solved using CMS;
- use CMS in the classroom to conduct intermediate calculations that take a large amount of time;
- offer students tasks in higher mathematics of a professional orientation, which should be solved using CMS;
- gradual complication and expansion of the use of CMS in the teaching process;
- develop students' motivation to master independently the ability to apply CMS in the learning process;
- use CMS to visualize the process of learning mathematics.

The experts specify that the problem of choosing CMS and supporting a large installation base is solved through the use of network technologies, when a user, using specialized client software, accesses the server side of CMS, where user's commands are executed, and the result is returned to the client software. Such services are provided in particular by MATLAB Web Server, webMathematica, and wxMaxima. Although not every CMS include built-in network tools, for those of them, in which the command interface is supported along with the visual one, it is possible to create a network add-in.

According to the experts, one of the forms of organizing educational activities related to the acquisition by students of practical skills in the corresponding field of knowledge using ICT tools is a computer-oriented practical lesson. This lesson, according to one of the experts, "is based on a combination of traditional and computer forms of training and knowledge control and is focused on solving problems ensuring continuity between practical, laboratory, and lecture classes on the basis of internal and interdisciplinary logical connections".

The experts note that the quality control of knowledge can be carried out both in the audience and beyond using the Internet. The use of CMS, test programs, and test modules in training support systems allows students to conduct self-control and teachers to automate the teaching process.

According to the experts, the use of ICT tools significantly expands opportunities of a teacher through the implementation of online communication with students for the purpose of timely consultation on problematic issues. Such communication is carried out using various ICT

tools, among which the use of e-mail, platforms for interactive communication, and social networks for communication in groups stand out. Web-based tools allow teachers to communicate with students in one of the following ways: online, solving a problem with quick response to questions using instant messages, using e-mail to support prolonged dialogs (for example, throughout the whole semester or school year), and conducting virtual discussions in the classroom using a discussion board or Web conferences. Furthermore, with the help of ICT, a teacher can conduct individual and group consultations outside the university. Using video recordings of classes, a teacher can demonstrate examples of problem-solving, which will allow students to learn the taught material better.

The experts emphasize that for a quality training process, it is necessary to choose such teaching tools that will ensure the best integration of classroom and extracurricular education. Among them, paper and e-books and aids, teaching materials posted on the Internet, educational audio and video materials, support systems for mathematical activities, test systems, simulators for developing skills and abilities, digital libraries, and reference books, etc. stand out.

Summing up the discussion, the experts conclude that in the process of teaching higher mathematics to students at technical universities, there is a harmonious combination of classroom education with virtual, full-time education with distance, individual, and group education. At the same time, the teacher and students support both synchronous and asynchronous communication.

Conclusions

The systems of mathematical training of engineers currently have the following features: a high level of mathematization and computerization of general engineering and special disciplines; the content of mathematical training is professionally oriented and differentiated by the levels of initial training of students; ICT tools are widely used in teaching higher mathematics.

The emergence of a new type of hardware or software ICT tools affects the process of organizing training in higher mathematics at the present stage and creates the conditions for the implementation of web-based teaching of higher mathematics.

The results of the study confirm the hypothesis that the emergence of new ICT leads to changes

in the theory and methodology of teaching higher mathematics, which, in turn, leads to the emergence of new goals, means, forms, and methods of organizing the educational process.

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