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USE OF COMPUTER ALGEBRA SYSTEM MAXIMA IN THE PROCESS OF TEACHING FUTURE MATHEMATICS TEACHERS

Abstract. The article is devoted to the research of a problem of the application of computer algebra systems in the course of skill training of future mathematics teachers. The possibility of study organization for students of pedagogical institutions of higher education receiving "014 secondary education (mathematics)" speciality with the use of computer algebra systems is considered. The term "computer algebra system" is understood as the software which is intended for the solving of various mathematical tasks by means of a computer with a possibility of visualization of all stages of calculations. Proceeding from the fact that the computer algebra systems are actively used in educational process all over the world and informational educational environments in the course of teaching mathematical disciplines are created on their basis, it is possible to make a conclusion that the computer algebra systems are very important components of the process of training future experts. The current state of the problem of introduction and application of the computer algebra systems in the training of future mathematics teachers is investigated. The role of the computer algebra systems in teaching mathematics subjects and general natural sciences in pedagogical establishments of higher education is defined. Such computer algebra systems as MathCAD, MatLab, Maple, Mathematica, Maxima, SAGE, and Axiom are marked out among the most modern and successfully used systems aimed at solving mathematical tasks. Arguments in favour of the use of the free computer algebra system Maxima in educational and scientific activity of students are adduced in the article. Its main advantages and disadvantages are presented. The main functional of this system is considered which allows to optimize the time of the solution of various mathematical tasks, to adjust a conclusion of the received result, to perform staged verification of correctness of calculations.

Keywords: computer algebra system; free software; Maxima.

1. INTRODUCTION

An active development of technologies promotes their penetration into all spheres of human activity. In this connection, the role of information processes increases, the demand for information, the newest methods and technologies of its production, exchange, processing, accumulation, presentation and use are steadily growing. It causes the emergence of a variety of promising information and communication technologies, which are in great demand among modern mankind. Penetrating deeper into human activities, information and communication technologies do not bypass education. Their introduction into education significantly expands the possibilities of the educational process, reveals the depth of the subjects taught, helps to identify and reveal the individual abilities of the trainees through the formation of a scientific worldview, forms an

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understanding of the need for self-development and self-education, develops analytical and creative thinking, and broadens the understanding of the world around them [1]. In addition, the use of modern information and communication technologies in education contributes to the disclosure and development of students` individual abilities; the formation of their cognitive interests; gives them an aspiration for their self-realization, provides a comprehensive study of the phenomena of reality, shows the inextricability of the relationship between science, technology, the Humanities and art, encourages constant dynamic updating of the content, forms and methods of the teaching and upbringing processes [2].

Due to the introduction of information and communication technologies in education, there are wide opportunities for improving the educational process: explaining new material through its visualization; formation of practical skills in using modern information technologies both in educational activities and in everyday life; development of students` research skills and their independence; awareness of their place in modern society and so forth. According to many scientists and researchers (V. Bykov, Yu. Goroshko, M. Zhaldak, O. Semerikov, A. Spivakovsky, J. Trius, etc.), the main pedagogical tasks of using information and communication technologies in teaching of future teachers are:

- increasing the visibility of the educational material, which greatly facilitates its perception;
- the increased motivation to learn and cognition of new subjects of training;
- the disclosure and development of the individual creative potential of the students;
- the formation and development of learning activity culture;
- the intensification of the educational process, increasing its quality and effectiveness;
- the development of students' skills of experimental and research activity;
- the expansion and deepening of the content of the disciplines studied;
- the assimilation of the entire spectrum of concepts, operations and functions, the free operation of which is provided for in the content of the academic discipline.

However, the use of information and communication technologies in the educational process is not limited only to the solution of the pedagogical problems listed above, but also has considerable didactic possibilities for activating cognitive activity and practical skills, which are caused by in-depth study of a particular software [3].

Formulation of the problem. An inalienable and important element of modern information and communication technologies is technologies based on the application of all possible systems of computer algebra. The use of these systems to automate the process of solving certain problems becomes more and more relevant in various fields of activity. It is also important that computer algebra systems can be used as innovative pedagogical technologies, since they can be a medium for designing and using software tools to support the teaching of fundamental disciplines [4]. Especially it is necessary to highlight the use of computer algebra systems in the teaching of exact and natural sciences [5,6], as well as in scientific activities aimed at solving various problems [7]. One of the main obstacles that arise in the way of integrating computer algebra systems into the learning process is the fact that the prevailing part of them refers to proprietary commercial software. This greatly complicates their use in most pedagogical institutions of higher education. This is mainly due to the fact that despite the loyal price policy and discounts provided to educational institutions when acquiring computer algebra systems for educational purposes, the vast majority of educational institutions do not have the funds to acquire the number of licenses necessary for the organization of a full-fledged educational process. One of the main possibilities for solving this problem is the use of freely distributed systems such as Maxima, Sage, Axiom and the like.

It is understandable that insufficient funding of educational institutions encourages us to look for solutions to problems related to savings in the process of equipment purchasing and licensed software purchasing. Now there is a possibility of full-fledged provision of educational institutions with software products built exclusively on the basis of freely distributed software. Information and communication technologies are the most attractive technologies for educating future mathematics teachers from the emotional point of view, however, they are also professionally necessary. These

very technologies are most significant in the professional direction of the educational process of the pedagogical educational institution of higher education, therefore they are an important means of orienting future teachers to use information and communication technologies in training during professional activities and mastering professional skills. In this sense, the Maxima system leads to an increase in the cognitive activity of future specialists and the effectiveness of assimilation of the proposed disciplines [8].

Analysis of recent research and publications. Scientific research in the domain of the information and communication technologies implementation into education was initiated by A. Ershov and widely studied by Yu. Ramskii [7] and M. Zhaldak [6]. In the works of these scientists, as well as a number of other works, modern computer-oriented methodological teaching systems were studied which were oriented to a pedagogically expedient and balanced combination of the achievements of traditional methodological training systems and modern information and communication technologies.

The problem of integration of computer-oriented methodological teaching systems into the educational process in higher educational institutions was considered in the works of S. Rakov, Yu. Sinko, Yu. Trius and others. In his study, Y. Sinko examines the concept of computer algebra and the main software tools of foreign and domestic production in recent years, determines the role and place of computer algebra systems in the teaching of exact sciences [9]. Yu. Trius noted that computer mathematics can be defined as a set of methodological, theoretical, algorithmic and software tools designed to solve a wide range of mathematical problems with a high level of visualization of computations using computers [10]. At present, computer algebra systems become a powerful tool in the work of both professional mathematicians and those who use mathematics to build mathematical models in various fields of science. Nowadays in the world there is a huge amount of software, the use of which allows you to solve tasks of different complexity level with a sufficiently high level of visualization and various means of output of the result obtained with the help of a computer. This positively affects the motivation of students to study the material and gives impetus to the search for new algorithms for solving various mathematical problems [11]. However, the problem of choosing a system of computer algebra for teaching the disciplines of the mathematical cycle in pedagogical institutions of higher education, especially in the conditions of insufficient funding, remains quite weighty.

In the light of the foregoing, **the aim of the research** is to find the most suitable solution in choosing a computer algebra system for teaching the fundamental cycle subjects to students of Ukraine`s pedagogical institutions of higher education receiving "014 secondary education (mathematics)" speciality in the current conditions of limited funding, by introducing the possibilities of free computer algebra systems.

2. METHODOLOGY OF THE STUDY

According to the A. Kyverjalga`s classification [12], the following professional methods were used in the research methodology: general scientific, in particular, study and generalization of pedagogical experience; sociological in the questioning of graduate students, as well as methods for processing the results of the study.

The survey was conducted among graduate students of the Physics and Mathematics Faculty, who performed final qualification work. A total of 112 people took part in the survey. "Google Forms" – the tool for creation of online forms – was used for the questioning. Processing and visualization of the obtained results was carried out in the table editor "MS Office Excel".

3. RESULTS OF THE STUDY

3.1. Basic Provisions

Computer algebra systems are actively used in the educational process throughout the world. Creation of an educational environment in the process of teaching mathematical disciplines on their

basis is a very important component in the training of future specialists [13]. Among modern and most successfully used packages aimed at solving mathematical problems, both in numerical and symbolic forms, we can distinguish the following: MathCAD, MatLab, Maple, Mathematica, Maxima, SAGE, Axiom. The first two packages are oriented to numerous mathematical calculations. Packages Mathematica and Maple have a fairly developed means of symbolic transformation, moreover, possessing powerful numerical computation tools they are becoming increasingly popular [14]. Among computer algebra systems, in terms of evaluating their computing power, language facilities, ease of use and interpretation of results, Maple, MatLab, Mathematica and MathCAD are the undisputed leaders in their class, but belong to proprietary software. In our time, proprietary software is widely used in scientific research and has long been one of the most important components of the educational process. Such software has a user-friendly interface, implements most of the standard and special mathematical operations, powerful graphics tools and its own programming languages. For schoolchildren and students, these systems are indispensable in the study of exact and natural sciences, since they release them from complex calculations and focus attention on the essence of the method of solving a particular problem [15]. But the main drawback of these packages is the fact that they are commercial. That is, for the use of these software products, it is necessary to purchase a certain number of licenses, which significantly complicates the use of such systems in the educational process, since not every higher education institution can purchase the essential number of licenses, especially pedagogical educational institutions. Therefore, the only way for such educational institutions is to use free computer algebra systems, such as Maxima, SAGE, Axiom.

Earlier, the authors of the article explored the possibility of using modern free computer algebra systems in pedagogical institutions of higher education [8], [16], and also developed methods for using these systems to process research results at the physics and mathematics departments of pedagogical institutions of higher education.

3.2. Results of the study.

To determine the degree of usefulness of the study of computer algebra systems in the educational institution of higher education, we conducted a questionnaire annually, beginning in 2014, among the graduates of the Faculty of Physics and Mathematics of the State Higher Educational Institution "Donbas State Pedagogical University", who performed the qualification work. In total, 112 graduates took part in the survey.

The diagram in Fig. 1 shows information about the number of graduate students who used computer algebra systems to perform the necessary mathematical calculations writing their final qualification work.

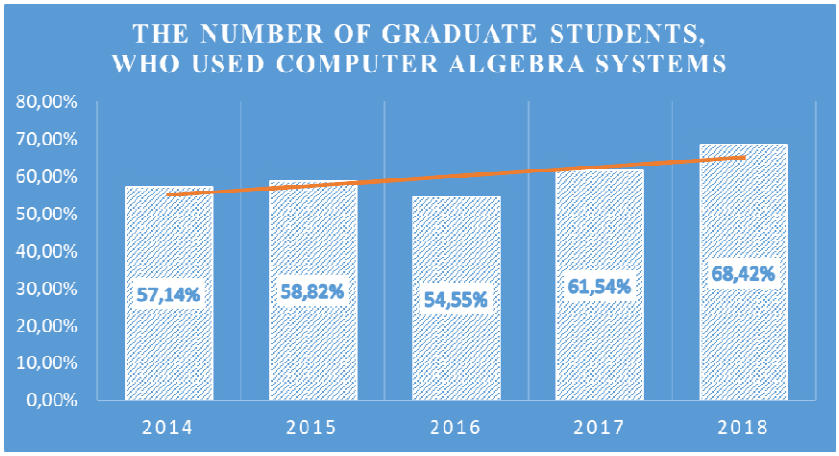

Fig. 1. The number of graduate students who used computer algebra systems to write qualification work

As we see from the diagram, the majority of interviewed students used different systems of computer algebra to prepare final qualification work, at the same time, there is a fairly large proportion of those who performed calculations manually. As the trend line shows, the percentage of graduate students performing manual calculations is getting smaller, but the speed of this process is rather low. After summarizing the results (Fig. 2) obtained from the questionnaire, it was found that 59.82% of the students surveyed used computer algebra systems, and 40.18% performed the calculations manually.

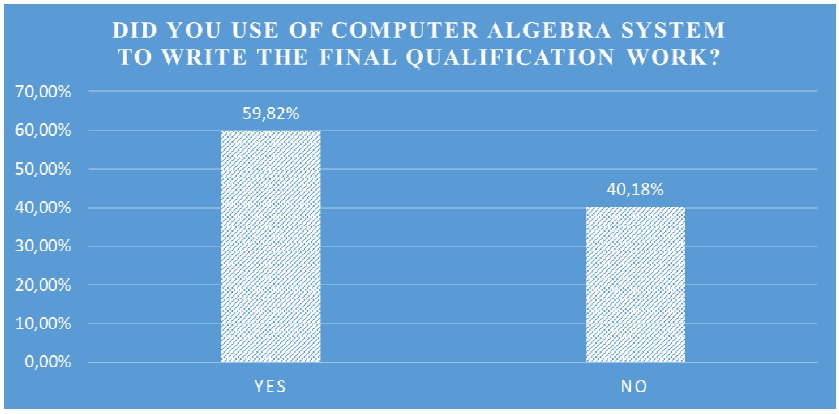

Fig. 2. The total number of graduate students who used computer algebra systems when writing their final qualification works, starting since 2014

Graduate students who did not use computer algebra systems were asked an additional question, in order to find out the reasons why they refused to use such software. In Fig. 3 we see that most of them (58%) simply do not have the necessary skills to work with computer algebra systems, and some of them (20%) even considered the possibility of using such systems for their calculations. Although, as it turned out, some graduate students (15%) prefer to perform the necessary conversions manually.

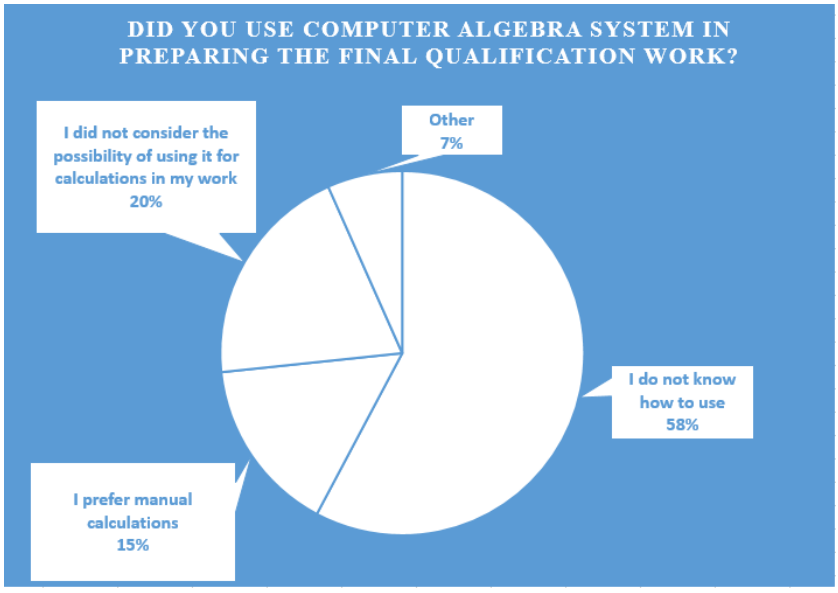

Fig. 3. The number of graduate students who used computer algebra systems to write final qualification work

In the course of the study, it was also determined that most of the graduate students who did not use computer algebra systems (Fig. 4) spent from 101 to 150 hours (46.67%) to perform the necessary calculations and present them in their works. The second largest part of students (31.11%) spent from 51 to 100 hours. More than 150 hours were spent by 15.56% of students, all

the rest (6.67%) spent less than 50 hours. As a result, most of the graduate students who used computer algebra systems (Fig. 5) fell within the time frame from 51 to 100 hours (47.76%), followed by a part of the students (23.88%) that fell within the time frame between 101-150 hours, less than 50 hours were spent by 20.9% of students and 7.46% spent more than 150 hours.

Comparing the diagrams in Fig. 4 and Fig. 5 it is easy to see that the number of graduate students who spent less than 50 hours is 14.23% higher than the number of those who are not using such systems. Similarly, it is 16.65% higher among those who spent from 51 to 100 hours. At the same time the percentage of those who used computer algebra systems among the graduate students who spent from 101 to 150 hours is much lower, namely by 22.79%. And twice less is the percentage of graduate students who spent more than 150 hours.

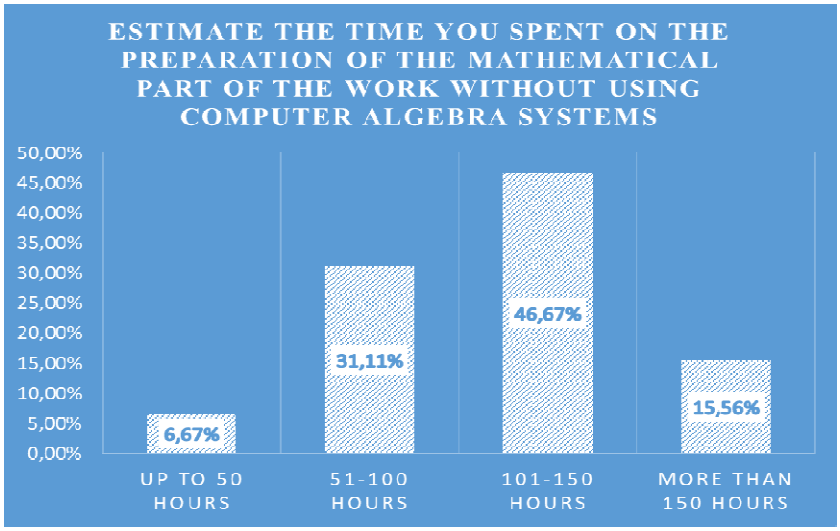

Fig. 4. Time spent by graduate students on the preparation and execution of the mathematical result of the final qualification work without the use of computer algebra systems.

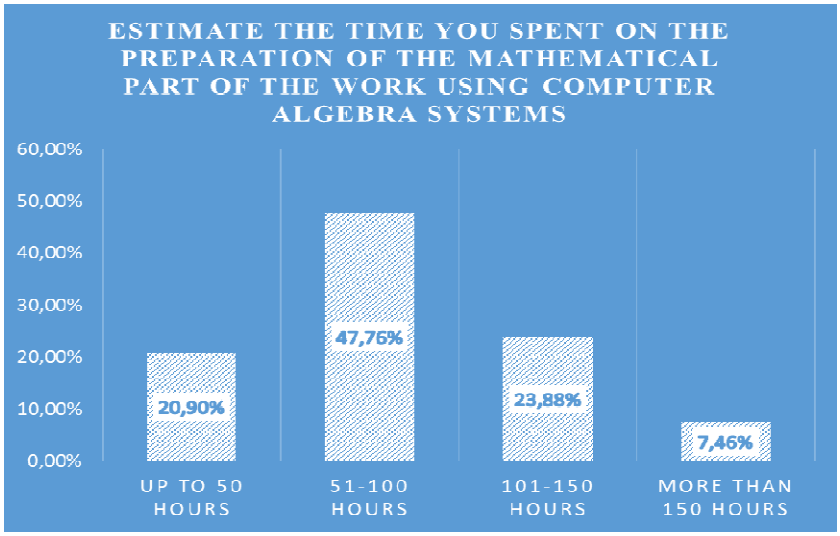

Fig. 5. Time spent by graduate students on the preparation and execution of the mathematical result of the final qualification work with the use of computer algebra systems.

Estimating the average time spent by graduate students from different groups, we found out that on average, a little more than 21 hours are saved during the preparation and execution of the mathematical part of the final qualification work (Fig. 6).

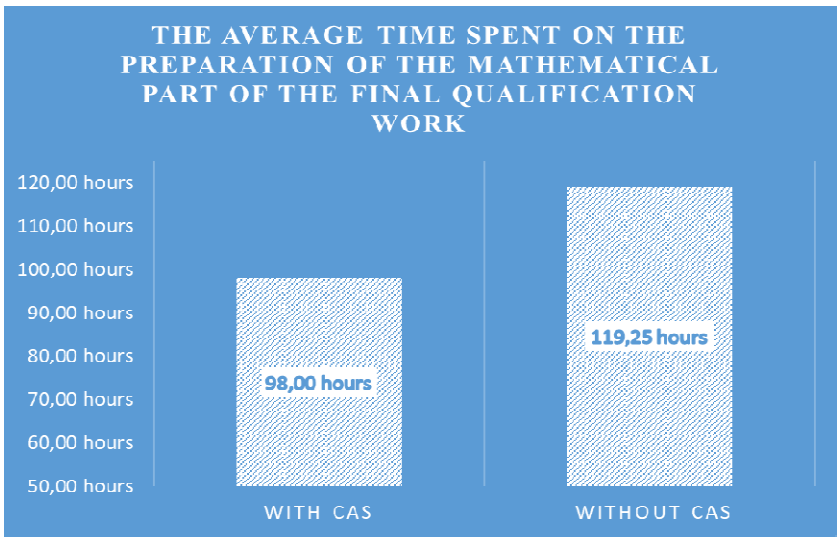

Fig. 6. The average time spent on preparing the mathematical part of the qualification work

Thus, it is easy to see that the skills of using computer algebra systems greatly save the time of students when performing intermediate mathematical calculations, and accordingly the study of such software products at the initial stage of the students' education is simply necessary. It remains only to determine the choice of an optimal free computer algebra system.

3.3. Advantages and disadvantages of using the computer algebra system Maxima.

One of the computer algebra systems is the Maxima system, which is essentially the development of the commercial Macsyma system developed by the Massachusetts Institute of Technology within the framework of the MAC project (funded by the DOE and other government organizations) and was the first universal system of symbolic computing. The architecture of this system was developed in 1968, and its programming began in 1969. Common Lisp was chosen as the programming language. Professor William F. Schelter from the University of Texas at Austin led the development and support of one of the versions of the system called DOE Macsyma. In 1998, William Shelter received permission from the Department of Energy to release DOE Macsyma's source code under the GNU GPL license, and in 2000 he created a project on SourceForge.net for supporting and further developing DOE Macsyma named Maxima [17].

The ideas implemented in the development of Macsyma were later used by such systems of computer algebra, as Mathematica, Maple and others. The Maxima system has a wide range of tools for performing analytical calculations, includes numerical methods and has developed tools for constructing graphic illustrations [15]. Users of this software have the right to unlimited installation, distribution and modification, as well as distribution of the results of the source code changes of this software. At the moment Maxima is released under Unix-compatible systems and for the operating system Windows. By itself, Maxima is a console program, and displays all mathematical formulas with text symbols. It has its positive factors. On the one hand, the Maxima system can be used as a core, using graphical interfaces on top of it, and on the other - Maxima itself, without any add-ins is undemanding to hardware and can work even on the weakest personal computers, which is very relevant, in conditions of limited state funding of higher education institutions which do not have the internal financial capacity to update the computer fleet, but have a need for computer algebra systems.

Maxima supports the following areas of mathematics:

1. operations with polynomials (manipulation of rational and power expressions);
2. finding Taylor polynomials and creating a graphical demonstration of the function schedule in a row, depending on the degree of the polynomial;
3. research of functions (including those specified in the table) and the construction of their graphs;

4. geometric problems with parameters;
5. computations with elementary functions, including logarithms and trigonometric functions;
6. computations with special functions, including integrals and elliptic functions;
7. calculation of limits and derivatives;
8. analytical calculation of definite and indefinite integrals;
9. solution of algebraic equations and their systems;
10. solution of integral equations;
11. operations with power series and Fourier series;
12. operations with matrices and lists;
13. solution of a wide range of problems of linear algebra;
14. solving interpolation problems;
15. statistical calculations;
16. operations with tensors;
17. number theory;
18. theory of groups;
19. theory of graphs and others [15], [18].

Given the ease of mastering the computer algebra system Maxima, its use in teaching the disciplines of the mathematical cycle in the pedagogical institution of higher education is advisable to begin with the second semester of training, when students have already studied the basics of mathematical analysis, linear algebra and elements of discrete mathematics. The study of this package should begin with an introduction to syntax, alphabet, 2D and 3D graphics and the possibilities of using them in solving mathematical problems. Particular attention should be paid to programming. In the future, the computer system Maxima can be used for training in such disciplines as Elementary Geometry, Computational Methods, Mathematical Analysis, Differential Equations, and other disciplines from the cycle of mathematical, natural-science, professional and practical training [4].

Using the system of computer algebra Maxima makes it possible to free students from a significant amount of routine computing in solving various mathematical problems, which often becomes an obstacle that prevents a deeper understanding of key ideas and methods for solving these problems. The use of this system could significantly reduce the time spent on preparing course and diploma projects. Also, the use of the computer algebra system Maxima will provide significant assistance to students in verifying the results of tasks solved manually. Graphics, developed in this computer algebra system, will visually present the results of solutions.

Obviously, at the initial stage of implementation of Maxima system in the educational process there will be a number of problems. Firstly, the use of this system at the initial stage is connected with the study of the principles of operation of all necessary commands and variables, and with the study of the system interface. Secondly, the lack of the necessary knowledge and skills of teachers, which may entail the need to improve their skills in the relevant courses (or you can organize similar courses on the basis of their school). Another important problem of using the computer algebra system Maxima in teaching the disciplines of the mathematical cycle is its insufficient methodological support. It should be noted that there is a lot of literature in which the functionality of the packages is described, but at the same time, there is not enough methodological literature on the use of software products in the learning process.

Consider now the main advantages of the computer algebra system Maxima. In our opinion, the most significant are:

- the possibility of free use of the system (the computer algebra system Maxima refers to free and open programs and is distributed on the basis of the GNU GPL license);
- cross-platform (in particular, the ability to work under the operating systems Windows and Linux (including Android));
- a small program size (in the established form with all extensions, the size is not more than 100 megabytes);

- the ease of installation on workstations in computer classes;
- the support for cloud technologies (it is possible to work with the system via the Internet, using the usual browser);
- the ability to work both in the console version of the program and using one of the graphical interfaces (xMaxima or wxMaxima);
- the wxMaxima extension included in the package provides a fairly user-friendly interface;
- if necessary, you can create your own functions (including using the source code of the functions included in the package);
- there is a program interface in Russian;
- included in some Linux distributions and is available in repositories;
- a fairly wide range of tasks to be solved;
- the availability of reference manual for working with the program.

Let's consider the main weak points of the computer algebra system Maxima:

- to work with this system, it is necessary to study quite a few commands and constants;
- the results of computations are rarely absolutely accurate in the mathematical sense, since in operations with real numbers they are rounded off;
- the conditions for the appearance of errors and failures are not always clear - their evaluation, and, accordingly, the elimination are rather complex theoretically and laborious in practice;
- the ability to build complex graphs or visualizations is much inferior to other systems of computer algebra;
- In solving complex problems, the result largely depends on the level of knowledge of mathematics (or on the experience of using similar systems) by a particular student, since preliminary transformations must be performed independently;
- the implementation of numerical methods (for example, the solution of differential equations) is based on approximate algorithms, which with accumulation of errors, can lead to incorrect solutions or to complete system hang up [15].

It should also be mentioned that the subsystem of the console version of the Maxima package (including the one in the browser-based shell) is used in the computer algebra system Sage, which is mainly oriented to numerical calculations and is one of the most powerful freely available systems of computer algebra [16].

4. CONCLUSIONS AND PROSPECTS FOR FURTHER STUDIES

Having analysed a wide range of literature devoted to the introduction of the latest information and communication technologies in education, we can conclude that the intensity of research into such implementation in the process of studying the exact and natural sciences in educational institutions is growing.

The skills of using computer algebra systems make it possible to significantly save students' time during intermediate mathematical calculations, and accordingly the need for introduction and study of such packages at the initial stage of the students' education is great. One of the optimal systems for this purpose is the computer algebra system Maxima. This system is able to compete almost on an equal footing with the capabilities of market leaders - the Maple and Mathematica systems, has a modern graphical interface and excellent functionality. The use of the computer algebra system Maxima can solve a wide range of problems, from simplification of algebraic expressions to graphs animation and step-by-step visualization of the solution process. It reduces the time of solving problems, adjusts the output of the result and organizes the necessary level of visualization, as well as performs a step-by-step check of the correctness of the calculations. This, ultimately, makes the Maxima system one of the main means of submitting material for the study of disciplines of the mathematical cycle by teachers of pedagogical institutions of higher education when training students in the speciality "014 secondary education (mathematics)". Also, the

specificity of the computer algebra system Maxima suggests that the use of it will not only improve the efficiency of teaching students in exact sciences, but can also contribute to a gradual transition to solving non-standard problems of a creative nature and can be used in teaching students of other specialties.

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ВИКОРИСТАННЯ СИСТЕМИ КОМП'ЮТЕРНОЇ АЛГЕБРИ MAXIMA В НАВЧАННІ МАЙБУТНІХ УЧИТЕЛІВ МАТЕМАТИКИ

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Анотація. Стаття присвячена дослідженню проблеми використання систем комп'ютерної алгебри в процесі професійної підготовки майбутніх учителів математики. Розглянуто можливість організації навчальної роботи студентів, що навчаються на спеціальності «014 Середня освіта (математика)» в педагогічних закладах вищої освіти з використанням систем комп'ютерної алгебри. Під терміном «система комп'ютерної алгебри» потрібно розуміти програмне забезпечення, призначене для вирішення за допомогою комп'ютера різних математичних задач з можливістю візуалізації всіх етапів обчислень. Виходячи з того, що системи комп'ютерної алгебри активно використовуються в навчальному процесі в усьому світі і на їх основі створюються інформаційні навчальні середовища в процесі викладання математичних дисциплін, можна зробити висновок, що системи комп'ютерної алгебри є досить важливою складовою процесу підготовки майбутніх фахівців. Досліджено сучасний стан проблеми впровадження та використання систем комп'ютерної алгебри в навчанні майбутніх учителів математики. Визначено роль систем комп'ютерної алгебри в викладанні дисциплін математичного та загального природничо-наукового циклу в педагогічних закладах вищої освіти. Серед сучасних і найбільш успішно використовуваних пакетів, орієнтованих на розв'язання задач математичного характеру, можна виділити MathCAD, MatLab, Maple, Mathematica, Maxima, SAGE, Axiom. У статті наведено аргументи на користь використання вільної системи комп'ютерної алгебри Maxima в навчальній і науковій діяльності студентів. Представлені її основні переваги та недоліки. Розглянуто основний функціонал цієї системи, що дозволяє оптимізувати час вирішення різноманітних математичних задач, налаштувати виведення отриманого результату, виконати поетапну перевірку правильності проведення необхідних розрахунків.

Ключові слова: система комп'ютерної алгебри; вільне програмне забезпечення; Maxima.

ИСПОЛЬЗОВАНИЕ СИСТЕМЫ КОМПЬЮТЕРНОЙ АЛГЕБРЫ MAXIMA В ПРОЦЕССЕ ОБУЧЕНИЯ БУДУЩИХ УЧИТЕЛЕЙ МАТЕМАТИКИ

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Аннотация. Статья посвящена исследованию проблемы использования систем компьютерной алгебры в процессе профессиональной подготовки будущих учителей математики. Рассмотрена возможность организации учебной работы студентов, обучающихся на специальности «014 Среднее образование (математика)» в педагогических учреждениях высшего образования с использованием систем компьютерной алгебры. Под термином «система компьютерной алгебры» понимается программное обеспечение, которое предназначено для решения с помощью компьютера различных математических задач с возможностью визуализации всех этапов вычислений. Исходя из того, что системы компьютерной алгебры активно используются в учебном процессе во всем мире и на их основе создаются информационные учебные среды в процессе преподавания математических дисциплин, можно сделать вывод, что системы компьютерной алгебры являются весьма важной составляющей процесса подготовки будущих специалистов. Исследовано современное состояние проблемы внедрения и использования систем компьютерной алгебры в обучении будущих учителей математики. Определена роль систем компьютерной алгебры в преподавании дисциплин математического и общего естественно-научного цикла в педагогических учреждениях высшего образования. Среди современных и наиболее успешно используемых пакетов, ориентированных на решение задач математического характера, выделены MathCAD, MatLab, Maple, Mathematica, Maxima, SAGE, Axiom. В статье приведены аргументы в пользу использования свободной системы компьютерной алгебры Maxima в учебной и научной деятельности студентов. Представлены её основные преимущества и недостатки. Рассмотрен основной функционал этой системы, позволяющий оптимизировать время решения различных математических задач, настроить вывод полученного результата, выполнить поэтапную проверку правильности проведения расчетов.

Ключевые слова: система компьютерной алгебры; свободное программное обеспечение; Maxima.

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