The Method of Using the Maxima System for Operations Research Learning

Mariya Shyshkina[1], Uliana Kohut[2]

[1]Institute of Information Technologies and Learning Tools of NAES of Ukraine,
9 M.Berlynskoho St., Kyiv, Ukraine
shyshkina@iitlt.gov.ua
[2]Drohobych Ivan Franko State Pedagogical University, 24 I. Franko Str., Drogobych, Ukraine
ulyana3001@gmail.com

Abstract. In the article, the problems of using the systems of computer mathematics (SCM) as a tool to support the teaching and research activities in the field of informatics and mathematics disciplines training are investigated. The role of SCM in the process of bachelors of informatics training and special aspects of pedagogical applications of these systems in the "Operations research" study is defined. The aim of the article is the justification of the Maxima system use of in the process of "Operations research" teaching in pedagogical university as enchasing the investigative approach to learning and determination of the perspective ways of its introduction. The main characteristics of SCM Maxima and the ways of access organizing to it both in local and the cloud-oriented implementation are considered. The results of the pedagogical experiment on the Maxima application to support the investigative approach to operation research study and the analysis of its conclusions are reported.

Keywords: "Operations research", Maxima, learning tools, investigative approach, Cloud computing, mathematical disciplines, learning environment, educational university.

1 Introduction

1.1 Research objectives

In the modern information-educational environment there are new models of the learning activity organization, that are based on innovative technological decisions of environment infrastructure organization including the cloud oriented.

The question of adjusting the information-technological infrastructure of the educational institution to the necessities of users, and organization of facilities and services of this environment in order to realize as much as possible the pedagogical potential of modern ICT, to attain the increase of learning results and also the improvement of the process of research activity of the students the innovative approaches are in demand. These approaches are to provide the most advisable ways of access organ-

ization to systems of computer mathematics, that are among the leading types of learning tools of mathematics and informatics.

The teaching “Operations research” in the system of specialists of informatics training in the pedagogical university play the special important role as it combines both the fundamental concepts and principles of different mathematics and informatics disciplines and applied models and algorithms of their implementation. There are the basic research approaches to the processes of mathematical modeling, decisions making, and mathematical description of the basic concepts and principles of data processing that are the subjects of computer modeling in informatics.

The use of SCM in the process of “Operations research” studies allows (i) to change the accents in the selection of theoretical material, (ii) to increase the fraction of tasks on mathematical models construction of the real optimization tasks and their research by means of SCM; and (iii) to introduce the tasks on comparison of the results, obtained by means of the numeral methods of optimization, described by one of programming languages and builtin SCM tools, and their analysis at different input data, as well as the tasks on programming in the environments of mathematical packages of numerical methods of optimization and their research.

The aim of the article is the justification of the Maxima system use of in the process of “Operations research” teaching in pedagogical university as enchasing the investigative approach to learning and determination of the perspective ways of its introduction.

1.2 Problem statement

The analysis of the domestic and international experience of the use of ICT in the process of informatics disciplines learning testifies that such class of ICT-based learning tools as the systems of computer mathematics(SCM) constantly attracts attention of researchers 1, 2, 3, 4. These systems, that are complex, multifunctional, powerful enough and at the same time simple in the use, become irreplaceable in maintenance of various processes of numerical accounts, patterns visualization, realization of symbol operations, algorithms and procedures 5, 4. SCM is the environment for the projecting and use of programming tools of the maintenance of informatics disciplines teaching, forming innovative pedagogical technologies.

In recent years, informatics disciplines learning tools and technologies have obtained a further development, in particular based on the concept of cloud computing. This conception significantly changes the existing views on the organization of access and integration of applications, so there is a possibility to manage larger ICT infrastructures, that allow to create and to use both individual and collective "clouds" in a cloud-oriented educational space 6, 5.

Localization of such tools for educational purposes as SCM "in the cloud" is perspective direction of their development, when there are more possibilities of adapting the teaching environment to academic achievement, individual needs and goals of the learners. The "spectrum" of research activities is expanding both due to the fundamentalization of IT disciplines and the content of teaching as well as extending access to research tools. In this regard, we must pay attention to issues of grounding theoreti-

cal and methodical bases of introduction and use of SCM, the definition of advantages and disadvantages of different approaches to deployment, research and analysis of the experience of their implementation.

Methodical peculiarities of teaching optimization methods and "Operations research" using WEB-SCM are analyzed in the work of Trius Y. V. 7. The graphical interface of SCM Maxima for modeling animations is described in detail in the work of Bugaets N.O. and examples of creating the animation evidentness models and their use are made for development of educational-research abilities 8.

The methodical aspects of using SCM Maxima in the process of "Operations research" teaching comes to the fore. It is aimed at the forming students' ICT-competences, including in a cloud-based environment due to: the acquaintance with functional characteristics of SCM Maxima; developing skills of mathematical research of the applied tasks, in particular, the construction of mathematical models; mastering programming in the SCM Maxima; obtaining the necessary knowledge base for studying other disciplines; increasing the level of informatics acquirement by means of the extensive use of SCM and cloud-oriented systems in the educational process and research work.

1.3 Research Methods

The study is based on the methods of theoretical analysis, generalization and systematization of scientific facts about the pedagogical processes and phenomena, methods of system analysis and modeling, pedagogical observations and generalization of pedagogical experience, as well as the results of the pedagogical experiment. The study was carried out in the framework of the implementation of the planned research undertaken in the Institute of Information Technologies and Learning Tools of NAES of Ukraine and the Department of Informatics and Computing Mathematics of the Drohobych Ivan Franko State Pedagogical University. In the process of research the scientific-methodical principles of using the cloud-based component on the basis of the Maxima system in the process of informatics disciplines teaching for computer specialists have been grounded and analysed.

Such interdisciplinary methods and procedures are used in informatics as analysis and synthesis, induction and deduction, visualization and formalization, algorithmization and programming, informative-logical, mathematical and computer modeling, program management, expert evaluation, identification and others. It is necessary to acquire them in complex, otherwise there is not a sufficient level of mastering the material of informatics disciplines.

2 Results and Discussion

2.1 The most important features of the Maxima system from the didactic process point of view

In the conditions of informative society formation it is very important to prepare highly skilled specialists, capable to undertake productive work in this society. Therefore

it is necessary to search for new methodological approaches to organization of learning that would assist the deep mastering and understanding of basic concepts, rules, principles and methods of disciplines studies, their relationship to contiguous disciplines, and ways of their use in practice. The perspective direction is the integration of the systems of computer mathematics in the process of "Operations research" teaching. These systems may help, on the one hand, to automate some routine actions, focusing students on mastering the concepts and principles that are studied, and on the other hand, to identify the interdisciplinary links of various disciplines, examining how certain fundamental concepts are implemented in applications.

The use of the cloud-based tools of SCM design is a significant factor in the expansion of access to them in the process of teaching and research activities in the field of informatics and mathematics. If research activity happened only in specially created situations in the case of application of a local version of the tool, more attention can be paid to the independent work with using a cloud-oriented version, and research activity is extended outside the classroom time 5.

The use of mathematical packages to solve practical problems involves (i) understanding the problems of the educational discipline for proper use of SCM; (ii) understanding the methodology of developing the algorithm from the mathematical ideas to the formulation and the ability to apply this methodology; and (iii) the ability to carry out grounding and estimation of the algorithm complexity at run-time and memory requirements [4, p. 138].

For scientific purposes the choice of SCM depends on the input data and result to be ob-tained. For example, the analytical model of the investigated phenomenon or object is more interesting for a physicist-theorist, so it is better to use the packages, such as Mathematica, Maple and Maxima. Physicists-experimenters would rather use the MATLAB system for large data sets processing 4, p. 138].

Special attention should be paid to Maxima system, as it is easy in learning, in solving the problems does not yield to such systems as Maple and Mathematica and is freely distributable. It is equipped with a menu system that allows performing symbol con-versions, to solve equations, to compute limits, derivatives, integrals and the like, not knowing the language for the description of the commands to perform these actions. Therefore the Maxima system can be used for informatics and mathematics disciplines learning even on the first course of pedagogical university 4. Maxima system application will not cause any difficulties for students in solving tasks of mathematical analysis and linear algebra – the students are required only to select a menu item and enter the expression. However, for programming in Maxima system one needs knowledge of language and syntax, as well as certain commands [4, p.138].

"Operations research" teaching of pre-service specialists requires special attention as it combines both the fundamental concepts and principles of different mathematics and informatics disciplines and applied models and algorithms for their application.

The goal of SCM using in the process of pre-service specialists training in Informatics is the formation of the ability for successful using the information technologies in their professional activities, creative approach to solving non-standard problems, deep mastering the fundamentals of the disciplines. For this purpose the methodology of SCM using in the process of "Operations research" teaching was developed, aimed

at (i) the formation of the professional competences of future specialists in Informatics that will give an opportunity in the future to adapt oneself to the requirements of informative society; (ii) the development of the creative approach to solving non-standard tasks; and (iii) the formation of mathematical skills needed for analyzing, modeling and solving theoretical and practical problems with application of SCM 5. The use of this technique was the subject of the present experimental studies with the application of both local and cloud-oriented implementation of SCM Maxima.

One of the important use of SCM Maxima in scientific investigations and at the mathematics and informatics disciplines learning at higher school is the solution and study of the optimization problems arising in various fields of human activities.

Due to the introduction of SCM Maxima into the "Operations research" teaching process the opportunity is occurred to focus students on key concepts, principles, approaches, releasing time and efforts that are spent on the software establishment, maintenance, and even greatly to mitigate the real spatial and temporal boundaries of the implementation of access to necessary electronic resources. This approach develops interdisciplinary links, assists the deep study of material, and extends possibilities of independent research, the combination of theory and practice, knowledge integration concerning the various departments and levels of computer education 4, 5.

For this purpose the technology of "virtual desktop" may be applied, where the data storage and processing are happened in the data center. Also, for a user, the work with cloud supplements, appealed via the Internet browser, does not differ from the work with software installed on a desktop of the user's personal computer 5.

The use of software that is installed on the student's virtual desktop (i) does not require spending educational time on installing and updating, (ii) the conditions for a more differentiated approach to learning are created, and (iii) provides the opportunity to focus on the basic material study 5.

The necessity to use SCM in the educational process is also caused by the fact that working with them provides students with the real opportunity to acquire skills to solve practical problems using SCM on the known scheme: setting of the problem →defining modeling goals → mathematical model development → election of mathematical method and algorithm of problem solution → implementation of mathematical model using SCM → calculations → analysis of the results obtained and their interpretation → making the decision.

A large number of practical problems are studied within the discipline "Operations research", which are easy to interpret as optimization problems on graphs. The examples of such tasks are (i) searching for the shortest route between two settlements, (ii) determination of the maximal admission characteristics of the oil pipeline, and (iii) scheduling the execution of the project works etc.

When solving optimization problems on graphs the interdisciplinary relationships of informatics, mathematics, economics and other disciplines are realized that contributes to the intellectual development of students on the basis of forming ideas about the integrity of vision of the world, ensures the formation of skills not only declarative but also procedural knowledge. The use of graph theory for the problems solution by students develops their ability to represent the conditions of the problem in the lan-

guage of graph theory, and then to interpret the solution in terms of the original problem.

The possibilities of using Maxima system to solve optimization problems on graphs are wide enough. A student, using SCM Maxima, solves the problem set before him, and thus he doesn't have the psychological barrier in the application of mathematical apparatus, and besides, he realizes also, what material is necessary to be repeated (or to be learnt). The solution of problems of applied nature (including, in particular, optimization problems on graphs) using a SCM provides the possibility of formation of the professional competencies. The interest is also the research of optimization theory problems, in particular the implementation of the numerical methods, both conditional and unconditional optimization using SCM Maxima. This, in turn, contributes to the improvement of programming skills.

Studying the section "Models of the dynamic programming" students are offered to solve the problems which demand using Maxima commands and functions or creating their own procedures and functions. This in turn contributes to the improvement of programming skills. For example, when solving the problem of dynamic programming about a backpack, students perform research, creative work, and its routine is completed using the computer.

The main stages of the solution of such problems are the problem setting (providing the objective function, optimality criterion, limitations, and accuracy of the solution) and analysis of the obtained results. The students obtain the system basis in solving problems, and they see the relationship between the content of various academic disciplines.

Summarizing the consideration of the course "Operations research", it should be noted that a wide set of tools for computer support of analytical, computing and graphical operations make the system of computer mathematics one of the main tools in the professional activities of mathematicians and programmers. The studies using Maxima system combine algebraic and computing methods. In this sense, SCM is the combining link between mathematics and computer science, where the research focus both on the development of algorithms for symbolic computation and data processing and the creation of the programs to implement these algorithms.

2.2 The characteristics of the Maxima system both in local and cloud-based version.

The Maxima system works on all modern versions of operating systems Linux and UNIX, Windows 9x/2000/XP" [4, p. 140]. In particular, the cloud-based version of the Maxima system was implemented in the Drohobych Ivan Franko State Pedagogical University. It was installed on a virtual server with operating system Ubuntu 10.04 (Lucid Lynks). In the repository of this operating system, there is a version of the Maxima system based on Emacs editor that was installed on the virtual student’s desktop 4, 5.

Besides, all the basic steps with this software product can be performed also in the environment with a graphical interface wxMaxima based on wxWidgets under Windows operating system 4, 5.

Among the mathematical packages the Maxima system owns wide enough possibilities at the implementation of symbol calculations. It is, in fact, the only one of freely distributed open systems, that does not yield the commercial SCM Mathematica and Maple. Maxima system is distributed under the license of GPL and is available to users of operating systems Linux and Windows 4 , p. 139].

2.2.1 Using the Maxima system under OS Windows

Maxima system works on all modern versions of operating systems Linux and Unix, Windows 9x/2000/XP. Consider the work with Maxima system with graphic interface wxMaxima GUI, based on wxWidgets, under Windows operating system 4, p. 140].

2.2.2 Using the Maxima system under OS LINUX

Working with the Maxima system in OS Linux may occur in different ways. Working with remote desktop based on OS Ulteo (a Linux distribution created on the base of Ubuntu), it is convenient to use the texmacs environment, which is installed as a static application on the OS 4, 5. OS Ulteo can be installed on one of the computers of a local network, on a virtual machine created on VMW products, on a virtual machine in OS AWS or some other similar network systems. The experience of using the Maxima system, which was installed on the cloud server, is more thoroughly described in 5.

Texmacs includes the work with several systems, one of which is the Maxima system. To create a session (i.e. insert object)in Maxima one must consistently choose the menu Insert – Session – Maxima. Then an active line appears for entering commands of the Maxima system.

More thoroughly experience of using SCM Maxima in the cloud-oriented environment is described in the "Methodical recommendations on the use of the cloud-oriented component based on the Maxima system in the informatics disciplines studies" 5.

The purpose of using SCM in the process of operations research learning is the fundamentalization of training and mastering the fundamental principles of the discipline. Here is the example of the laboratory practicum on "Construction of the frame of minimum cost, Prim algorithm" using the methods of appropriately selected tasks and demonstration examples that are solved using the cloud-oriented component of the learning environment on the basis of the Maxima system. This task can be carried out also using the local version, so the course of the solution is accompanied by illustrations, which can be obtained in any of the versions of the system, and by the interfaces obtained during the cloud component implementation.

After introducing the main theoretical positions on the subject and Prim algorithm students are offered the following example 10, 11.

At the end of each laboratory work they are offered the tasks for independent work.

Individual tasks are divided into three levels of complexity. The level of complexity of the assignment for execution is selected by the student independently. The task of the first level of complexity corresponds to the reproductive level of mastering

knowledge. To solve problems of the second level of complexity, the heuristic nature of the intellectual activity is necessary. The third level of complexity includes tasks for which a creative approach is necessary. The tasks are formulated in such a way that to solve them one must have elements of divergent thinking. Divergent thinking is usually inherent in creative individuals, inclined to create new combinations of those elements, others use only the usual way.

Each laboratory work is accompanied by a list of questions for self-examination and a number of tasks for performing during independent work of students. The main task is to form the practical skills of future specialists to formalize tasks and solve them with the help of SCM tools.

Thus, the method of using SCM Maxima as a means of training the study of the operations of future computer specialists can be summarized as follows.:

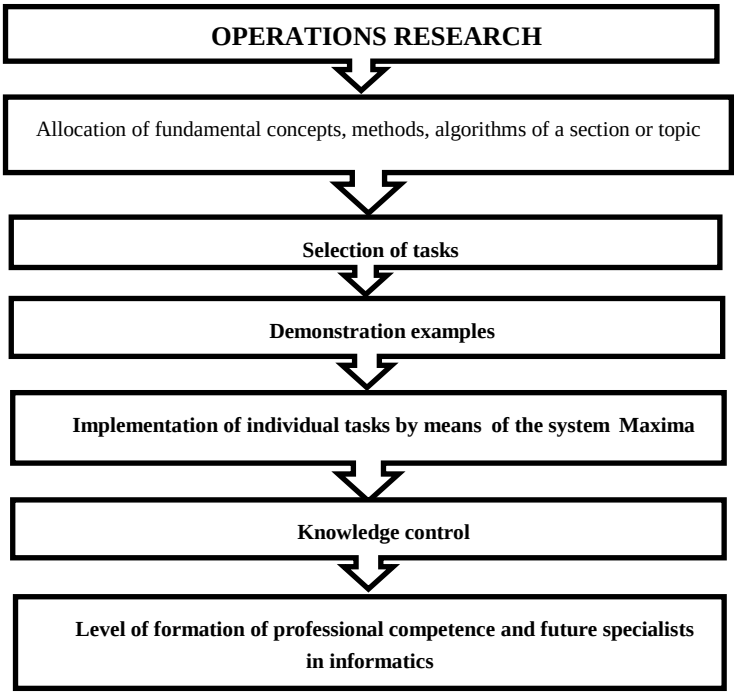

Fig. 1. Scheme of the stages of designing a computer-oriented environment using the system Maxima

The peculiarity of the developed methodology is the use of a systematic approach to the implementation of SCM in the process of studying operations research and their use to provide interdisciplinary links in the training of future IT specialists.

From the given example it is clear that due to the application of SCM Maxima in the process of "Operations research" teaching there arises the opportunity to carry out the necessary calculations. This gives the students the opportunity to use the greater part of educational time for (i) studying methods of applied problems solution, or even their development, (ii) acquiring the skills of mathematical models construction,

(iii) interpreting and analysing results of computing experiment, which lead to a deeper understanding of fundamental concepts that are studied. The use of SCM Maxima provides the ability (i) to provide adequate educational, methodical and scientific-research activities, (ii) to implement innovations into the educational process, (iii) to realize the interdisciplinary principle, and (iv) to combine independent work with various forms of collective activities.

The main stages of the solution of such problems is the problem setting (definition of the objective function, the optimality criterion, the limitations, the accuracy of the solution) and analysis of the obtained results. The students obtain the system approach basis in solving problems, and they see the relationship of the content of various academic disciplines studies.

Summarizing the consideration of the course "Operations research", it should be noted that a wide set of tools for computer support of analytical, computing and graphical operations make the system of computer mathematics one of the main tools in the professional activities of mathematicians and programmers. The studies using the Maxima system combine algebraic and computing methods. In this sense, SCM is the combining link between mathematics and computer science, where the research focus both on the development of algorithms for symbolic computation and data processing using computer and the creation of the programs to implement these algorithms.

2.3 Results of the pedagogical experiment using the Maxima system

During 2010-2014 the experimental research was being conducted. During the experiment they implemented SCM MAXIMA in the process of “Operations research” teaching concerning the students of the Institute of Physics, Mathematics, Economics and Information Technology of the Drohobych Ivan Franco State Pedagogical University (education and qualification level "Bachelor", area of knowledge – 0403 "System sciences and cybernetics", areas of training – 6.040302 " Informatics"). In the experiment, the specially worked out methodology of “Operations research” teaching using the Maxima system was tested. In the experiment, on his forming stage, 240 students participated. In the experiment they involved both the local version of the system, installed on the student computer desktop and the cloud-based version that was posted on the virtual desktop.

To reveal the students’ achievements the special test that included three kinds of tasks was formed. The task 1 is aimed at determining the level of formation of professionally-cognitive component of professional competence, task 2 – on the level of professional-activity component formation and task 3 - on creativity.

The experiment confirmed the research hypothesis concerning the increase of the level of professional competences development in the process of studies according to the worked out methodology. It also showed that by means of cloudy technology students can achieve greater access to the means of research activities (it is possible to attain expansion of access to research activity facilities).

Results formative stage of the pedagogical experiment in the control and experimental groups and comparative histogram distribution educational achievements stu-

dents on the results the final exam discipline "Operations Research" is shown in Fig. 2.

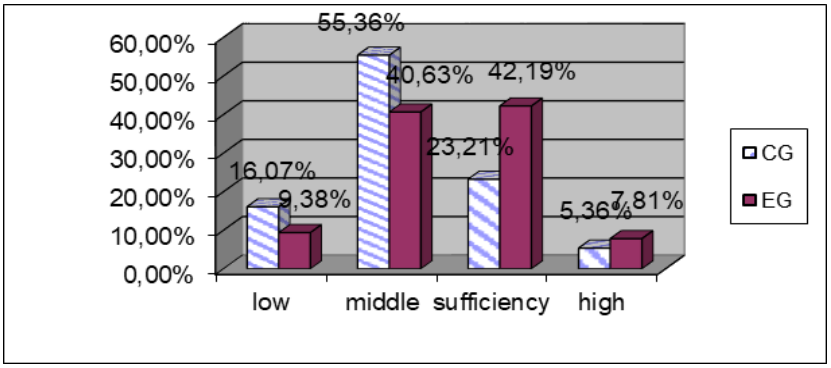

Fig. 2. A comparison of educational achievements of students on the results of final control the course "Operations Research" after the forming stage of the experiment

Processing of the experiment results and evaluation of the efficiency of the developed technique was carried out by methods of mathematical statistics 9. The objective of the experiment was to identify differences in the distribution of certain characteristic (the level of formedness of individual components of professional competence) comparing two empirical distributions according to the χ^2 - Pearson criterion, λ – Kolmogorov-Smirnov criterion 9, p. 4].

χ^2 - Pearson criterion. The samples in the study are random and independent. The measurement scale is C = 7 categories (1-39, 40-59, 60-66, 67-74, 75-81, 82-89, 90-100). The number of the degree of freedom v = C – 2 = 5.

The null hypothesis H0: the distribution of the estimates for the student residual knowledges concerning the use of systems of computer mathematics in the control (n1 = 56) and experimental samples (n_2 = 64) to the forming stage of the experiment do not differ (i = 0, 1, …, 6).

Q_{1i} – number of participants in the control group who scored i points;

Q_{2i} – number of participants in the experimental group who scored i points.

Alternative hypothesis H1: the distribution of the estimates for the student residual knowledges concerning the use of systems of computer mathematics in the control (n_1 = 56) and experimental samples (n_2 = 64) to the forming stage of the experiment differ (i = 0, 1, …, 6).The value of χ^2 is calculated according to the formula

$$T_{\exp} = \frac{1}{n_1 n_2} \sum_{i=0}^{C-1} \frac{\left(n_1 Q_{2i} - n_2 Q_{1i}\right)^2}{Q_{1i} + Q_{2i}}$$

Since the obtained value Texp< Tcritical (2,372723< 11,07) does not fall in the critical region [χ^2, +∞], this suggests that before the forming stage of the experiment the

level of students' residual knowledge concerning SCM using in the control and experimental groups do not differ significantly.

The level of students knowledge on the course "Operations research" as well as professional disciplines was checked according to the results of complex state examination to justify the influence of methodology of SCM using as "Operations research" teaching tools on the increase in the level of some components of professional competence.

Null hypothesis H_0: distribution of students estimations on "Operations research" in the control ($n_1 = 56$) and experimental samples ($n_2 = 64$) after the formative forming stage of the experiment do not differ ($i = 0, 1, \ldots, 6$).

Q_{1i} – number of participants in the control group who scored i points;

Q_{2i} – number of participants in the experimental group who scored i points.

Alternative hypothesis H1: distribution of students estimations on "Operations research" in the control ($n1 = 56$) and experimental samples ($n2 = 64$) after the formative forming stage of the experiment differ ($i = 0, 1, \ldots, 6$).

The calculation of χ^2 criterion for the experimental and control samples after conducting the formative stage of the experiment showed that Texp > Tcritical (30,20408> 11,07). This is the reason for rejecting the null hypothesis.

The acceptance of the alternative hypothesis suggests that these samples have statistically significant differences, i.e., the experimental method is more effective than the traditional one.

Taking into account that in the experimental groups the training of students was performed according to the developed methodology, it can be assumed that this contributed to the achievement of better results. Therefore, it is possible to speak of experimental confirmation of the hypotheses.

Summarizing, we conclude that the pedagogical experiment confirmed the hypothesis of the study. Analysis of the results indicates the increase in the level of formation of individual components of professional competence using the developed methodical system and, consequently, its effectiveness.

3 Conclusions and Prospects for Further Work

SCM implementation in the process of training of pre-service professionals in computer science provides an opportunity to intensify the educational-cognitive activity of students, assists to development of their creative abilities, mathematical intuition and skills of research activities realization. SCM systematic using contributes to students attitude toward a computer as to the means of solving professional problems. Such students gain more knowledge not only in mathematical disciplines but also in computer science. As a rule, they have no psychological barrier to using sophisticated software tools. On the contrary, they are attracted by the programs created at a high professional level, and they notice the unique application possibilities of such systems. SCM is an environment for learning tools projecting and, consequently, can be used for the creation of innovative pedagogical technologies. The perspective direc-

tion is using the tools of this type "in the cloud" when there are more possibilities of adaptation of the learning environment to the learning needs of the user.

The prospect of further research is to expand the range of research tasks that can be solved using the proposed cloud-based component, further testing and comparison with other cloud-centric software products on the basis of the certain system of indicators.

References

1. Kobylnyk, T.P.: Systems of computer mathematics: Maple, Mathematica, Maxima. Drohobych: Redaktsiino-vydavnychyi viddil DDPU imeni Ivana Franka, 316. (2008). (in Ukrainian)
2. Slovak, K.I., Semerikov, S.O., Tryus, Yu.V.: Mobile mathematical environment: current state and development prospects. In: J. NaukovyiChasopys M.P. Dragomanov NP, series 2 “Computer Oriented Learning Systems”, vol. 19, № 12, 102-109 (2012). (in Ukrainian)
3. Tryus, Yu.V.: Computer-oriented methodological training system of mathematical disciplines in higher education: dys. ... dokt. ped. nauk : spets. 13.00.02. Cherkasy, 649 p. (2005). (in Ukrainian)
4. Shyshkina, M.P., Kohut, U.P., Bezverbnyy, I.A.: Formation of Professional Competence of Computer Science Bachelors in the Cloud Based Environment of the Pedagogical University. In: J. Problems of Modern Teacher Preparation, vol. 9, part 2, 136–146 (2014). (in Ukrainian)
5. Shyshkina, M.P., Kohut, U.P.: Guidelines on the use of the cloud-based component with the Maxima system in the process of computer science courses learning. Drohobych : Red.-vyd. viddil DDPU im. I. Franka, 57, (2014). (in Ukrainian)
6. Bykov, V.: Cloud Computing Technologies, ICT Outsourcing, and New Functions of ICT Departments of Educational and Research Institutions. In: Information Technologies in Education, 10, 8-23, (2011). (in Ukrainian).
7. Tryus, Yu.V.: Using WEB-SCM in optimization and operations research methods training of students of mathematics and computer science disciplines". In: Innovative computer technologies in higher education : materials of the 4th scientific and pracyical conference, Lviv, 110-115. (2012). (in Ukrainian)
8. Buhaiets, N.O.: Modeling of animation visualization by means of graphical environment tools of the program Maxima. In: J. Information Technologies and Learning Tools, vol. 47, № 3, 67-79. http://journal.iitta.gov.ua. (2015).
9. Sidorenko, Ye.V.: Methods of mathematical processing in psychology. SPb.: Rech, 350, (2003) (in Ukrainian).
10. Shyshkina, M.P., Kohut, U.P., Popel M.V.: The Systems of Computer Mathematics in the Cloud Based Learning Environment of Educational Institutions. In: Batsakis, S. et al. (eds.) Proc. 13-th Int. Conf. ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017, 396– 405, CEUR-WS.org/ Vol–1844, ISSN 1613–0073, 396–405, online CEUR-WS.org/ Vol-1844. urn:nbn:de:0074-1844-4 (2017).
11. Shyshkina, M.P., Kohut, U.P.: Using the cloud-based component based on the Maxima system in the learning process of operations. In: J. Information Technologies and Learning Tools, vol. 57, № 1, 154-172. http://journal.iitta.gov.ua. (2017). (in Ukrainian).