# The Comparative Analysis of the Cloud-based Learning Components Delivering Access to Mathematical Software

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**Abstract.** In the article, the problems of the systems of computer mathematics use as a tool for the students learning and research activities support are investigated. The promising ways of providing access to the mathematical software in the university learning and research environment are considered. The special aspects of pedagogical applications of these systems to support mathematics and computer science disciplines study in a pedagogical university are considered. The design and evaluation of the cloud-based learning components with the use of the systems of computer mathematics (on the example of the Maxima system and CoCalc) as enchasing the investigative approach to and increasing pedagogical outcomes is justified. The set of psychological and pedagogical and also technological criteria of evaluation is used to compare different approaches to the environment design. The results of pedagogical experiment are provided. The analysis and evaluation of existing experience of mathematical software use both in SaaS and IaaS cloud-based settings is proposed.

**Keywords:** Cloud computing, systems of computer mathematics, learning tools, mathematical disciplines, learning environment, pedagogical university.

## 1 Introduction

### 1.1 Research objectives

In the modern information-educational environment there are new models of learning and research activity organization that are based on innovative technological solutions. The question of this environment facilities and services organization to enhance the pedagogical effect of modern ICT use comes to the fore. To attain the increase of learning outcomes and also the improvement of the students' research activity the innovative educational approaches are in demand.

A separate set of problems concerns to the application of software packages for the implementation of various mathematical operations, actions and calculations, these are the so-called Systems of Computer Mathematics (SCM), including Maple Net,

MATLAB web-server, WebMathematica, Calculation Laboratory, CoCalc and others [12, 14]. These systems are the most common types of mathematical software, being a part of the modern learning environment of educational institutions [4, 5, 7, 8]. The problems emerge when searching for promising methods and models of these systems use to enhance the pedagogical outcomes and provide the investigative approach to learning of engineering and mathematics disciplines.

**The aim of the article** is the justification of the cloud-based learning components design with the use of the systems of computer mathematics (on the example of the Maxima system and CoCalc) as enchasing the investigative approach to learning and pedagogical outcomes.

### 1.2 The Problem Statement

Nowadays, SCM make a significant impact on the content and forms of learning mathematics and informatics disciplines in higher educational institutions.

A separate set of problems relates to the use of mathematical software tools to enhance the investigative approach to learning. There are two factors in this respect that may significantly influence the investigative activity of students. Firstly SCM bring the possibility to address the basic notions of mathematics on the research level. Due to this the concepts of soft computation, discrete mathematics and others that are mainly computer oriented are included in the learning content. Secondly, SCM being the tool for computer modelling as the general method of investigation that is the fundamental base of all mathematics and computer science disciplines become the instrument of research.

There is a significant demand in the expansion of access to research activities tools while learning informatics and mathematics disciplines in educational universities as well as modernization of the learning environment with the use of current ICT tools, especially the cloud-based ones.

The progress in the area has provided new insights into the problems of educational learning environment development, bringing new models and approaches. These tools make a great impact on the learning data processing changing the content, methods and organizational forms of learning, lifting the restrictions or significantly improving access for all participants [10].

So, the modeling and analysis of the learning components design and deployment and available learning experience of its use in view of the current tendencies of the modern advance of the cloud-based mathematical software has come to the fore.

### 1.3 The Research Methods

The research method involved analyzing the current research (including the domestic, Ukrainian and foreign experience of the cloud-based learning services and mathematical software use in educational institutions in Ukraine and abroad), evaluation of existing approaches to software delivery, their advantages and disadvantages; comparison of promising ways of popular mathematical software implementation "in the cloud", examining the models and approaches, technological solutions and psycholog-

ical and pedagogical assumptions about better ways of introducing innovative technologies into the learning process. The cloud-based component with the use of the Maxima system was designed and elaborated within the study undertaken in 2012-2014 in the Institute of Information Technologies and Learning Tools of NAES of Ukraine devoted to the use of the SCM for the informatics bachelors training (U. Kohut). The learning component for math disciplines study was elaborated within the research undertaken in 2013-2016 (M. Popel). The special indicators to reveal ICT competence of educational personnel trained within the cloud-based learning environment and also the learning components quality evaluation indicators were elaborated within the research work devoted to the university cloud-based learning and research environment formation and development held in 2012-2014 in the Institute of Information Technologies and Learning Tools of NAES of Ukraine (M. Shyshkina). To measure the efficiency of the proposed approach the pedagogical experiment was undertaken in Drohobych Ivan Franko State Pedagogical University. The expert quality evaluation of the cloud-based components elaborated in the study was implemented. The approach and methodology were grounded within the research work "Methodology of the cloud-based learning environment of educational institution formation" that was held in the Institute of Information Technologies and Learning Tools of NAES of Ukraine in 2015-2017, Registration number 0115U002231 (coordinated by M. Shyshkina).

## 2 The State of the Art

The analysis of the domestic (Ukrainian) and international experience of ICT use of 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 an attention of researchers [4, 5, 8]. 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 [7, 8]. SCM is the environment for design and use of learning tools and components for informatics and mathematics disciplines, forming innovative pedagogical technologies.

In the recent years, the mathematics and informatics disciplines learning tools and technologies have been actively developed with the use of the cloud computing approach [4, 8]. 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 use both individual and collective "clouds" in a cloud-oriented educational space [1, 7].

Localization of such tools as SCM "in the cloud" is the perspective trend of their development when there are more possibilities for adapting the learning environment to educational demands, individual needs and goals of the learners. There is expansion of a "spectrum" of research activities due to both fundamentalization of informatics disciplines teaching content and expansion of access to research activities tools. In this regard, there is a need to consider the issues of theoretical and methodical

grounding of the SCM-based learning components design, revealing advantages and disadvantages of different approaches to their deployment and implementation.

The use of CoCalc cloud service in the learning process is possible by SaaS model, as this software is provided in such mode. The method of its use for several math disciplines study is considered in [3].

The Maxima system is provided in the local version. The cloud-based learning component with the use of this system was elaborated specially for the needs of learning several informatics disciplines, in particular, operations research study [8, 9].

The use of SCM Maxima in the process of operations research study aims at the forming of students' ICT-competences 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 environment; obtaining the necessary knowledge base for studying other math and informatics disciplines; increasing the level of informatics acquirement by means of the extensive use of SCM and cloud-based systems in the educational process and research work.

Methodical peculiarities of teaching optimization methods and operations research using WEB-SCM are analyzed in the work of Trius Y. V. [6]. The graphical interface of SCM Maxima for modelling animations is described in detail in the work of Bugaets N. O. and examples of creating the animation evident models and their use for development of educational-research abilities are given [2]. The problems of the right choice of SCM to support learning and research activity and elaboration of the most advisable methods of its use for math and computer science discipline so as to enhance the investigative activity of the students remain crucial in the area.

The Maxima system is provided in the local version still there is a way to install this system for the virtual desktop of the students using the IaaS cloud service model. Another way for the learning environment design may be realized with the CoCalc system which is provided by SaaS model [3]. The comparison and justification of two different approaches to learning components design need special attention.

## 3 The Research Results

The choice of SCM to support the investigative approach to learning depends on the input data and results to be obtained. 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 [8, 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 perform symbol conversions, solve equations, compute limits, derivatives, integrals and the like, without mastering the language for the description of the commands to perform these actions. Therefore, Maxima system can be used for informatics and mathematics disci-

plines learning even in the first course of the educational university [8]. Maxima system introduction 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 [8, p.138].

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 was provided only in specially created situations in the case of application of a local version of the tool, in case of the cloud-based version more attention can be paid to the independent work, and research activity is extended outside the classroom time [8].

For this purpose the technology of "virtual desktop" was applied, where the data storage and processing were maintained in the data center. Also, for a user, the work with cloud applications, appealed via the Internet browser, does not differ from the work with software installed on a desktop of the user's personal computer [8].

The use of software that is installed on the student's virtual desktop (I) does not require spending learning time on installing and updating, (II) the conditions for more differentiated approach to learning are created, and (III) provides the opportunity to focus on the basics of the teaching material [8].

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 the conventional 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 and not only declarative but also procedural knowledge. The graph theory problems solution develops the students ability to represent the problem in the graph theory language, and then to interpret the solution in terms of the original problem.

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 to be 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 pro-

cessing using computer and the creation of the programs to implement these algorithms.

### 3.1 The Results of the Pedagogical Experiment of Using Maxima for Learning Mathematics and Informatics Disciplines in Pedagogical University

During 2010-2014 the experimental research was being conducted. During the experiment, SCM MAXIMA was implemented 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 developed learning method of operations research teaching using Maxima system was tested. At the formative stage of the experiment, there was 240 students participated. The experiment confirmed the research hypothesis concerning the increase of the level of professional competences development in the process of study due to the use of the proposed learning technique [8, 10]. It was also showed that by means of the cloud technology the students can get better access to the research activity tools and facilities.

The special aspect of the study was the learning method application using the cloud version of the Maxima system that was posted on a virtual desktop. In the first case study (with the local version), this tool was applied only in special training situations. In the second case study (the cloud version) the students' research activity with the system extended beyond the classroom time.

The cloud-based learning component used in the experiment has undergone a quality estimation. The method of learning resources quality estimation developed in the joint laboratory of educational quality management with the use of ICT [7] was used and adapted for this study. The 20 experts were specially selected as having experience in teaching professional disciplines focused on the use of ICT and being involved in the evaluation process. The experts evaluated the electronic resource by two groups of parameters. The first group contained 7 technological parameters: ease of access; clarity of the interface; sustainability; support of collaborative work, ease of integration; mobility; and usefulness. The second group contained 9 psychological and pedagogical parameters: the scientific clarity; accessibility; fostering the intellectual development; problem orientation; personalization; adaptability; methodical usefulness; professional orientation; and feedback connection. The results of the quality parameters valorisation and the experts' concordance research are described in [9].

The problem was: is it reasonable and feasible to arrange the environment in a proposed way? For this purpose, there were two questionnaires proposed to an expert concerning two groups of parameters. The 20 experts estimated 16 parameters (there were 7 technological and 9 psychological and pedagogical among them). A four-point scale (0 (no), 1 (low), 2 (good), 3 (excellent)) was used for the questions.

The resulting average value was calculated for every parameter among the technological ones : "Ease of access" = 2.1, "Interface clarity" = 2.4, "Responsiveness" =

2.1, “Sustainability” = 2.56, “Support of Collaborative work” = 2.0, “Ease of Integration” = 2.0, “Usefulness” = 2.8, the total value was 2.3 [9].

The resulting average values for every psychological and pedagogical parameter was calculated as: “Scientific clarity” = 2.6, “Accessibility” = 2.7, “Fostering the intellectual development” = 2.5, “Problem orientation” = 2.8, “Personalization” = 2.8, “Adaptability” = 2.6, “Methodical usefulness” = 2.81, “Professional orientation” = 2,75, “Feedback connection” = 2,75. The total value was 2.71 [9].

The resulted average criterion of EER quality K=2,59. This characterises the resource quality as sufficient for further implementation and use [8, 9].

We can see that the results of the cloud-based component evaluation by the set of technological and also psychological and pedagogical indicators reveal the usefulness of this component to support the investigative approach to learning. The highest scores of the parameters’ values are “Scientific clarity” = 2.6, “Accessibility” = 2.7, “Fostering the intellectual development” = 2.5, “Problem orientation” = 2.8, “Personalization” = 2.8, “Adaptability” = 2.6, “Methodical usefulness” = 2.81, “Professional orientation” = 2,75, “Feedback connection” = 2,75. Just these kinds of indicators are the most important and “responsible” for the investigative activity of the learner. This fact also supports the hypothesis that the introduction of SCM into the learning process in particular within the cloud-based settings really extends the boundaries of the students research activities expanding it into the broader context.

### 3.2 The experimental Results of Using CoCalc for Learning Mathematics Disciplines in Pedagogical University

The application of cloud services leads to the emergence and development of forms of training organization focused on joint educational activities on the Internet. It is shown that cloud services in the training of pre-service mathematics teachers are expediently used as tools for:

- communication (synchronous – chats, voice and video; asynchronous – mail, forums),
- collaboration (data access, sharing and collaboration with other users),
- storage and processing of data.

The trends for using CoCalc in the training of mathematics teachers-to-be are as follows:

- organization of educational communication;
- support of individual and group forms of organization of educational activities (classroom and extracurricular);
- support of training management;
- providing visibility by constructing different interpretations of mathematical models, visualizing mathematical abstractions, etc.;
- providing accessibility and knowledge using the shared interface for access to environmental objects and reliable open source software;

– increase in time and spatial mobility; the formation of a single learning environment, the content of which develops in the learning process.

The control and experimental groups were formed as follows: the control groups (CG) included the students trained according to the traditional method of mathematics teachers' professional competencies formation; the experimental groups (EG) included students trained according to the author's technique for using CoCalc as a training tool for mathematics teachers' pre-service training.

Summarizing the obtained results of the confirmatory stage of the pedagogical experiment, it can be argued that:

– the vast majority of students and teachers have the opportunity to work with the cloud-based CoCalc service both at universities and at home;
– students in most cases do not use cloud services in the learning process, except for their use as cloud storage;
– students are interested in implementing the CoCalc cloud service in the learning process, but students are not ready for this;
– students at the beginning of the experiment showed a low level of information and technological and subject-pedagogical competencies formation, sufficient mathematical competencies;
– students and teachers use only free software tools (mostly local computer mathematics systems).

The following components of the subject, technological and professional-practical competencies were examined: subject-pedagogical, informational-technological and mathematical competencies. Each component was considered separately, and the values were calculated according to the levels: high, sufficient, average and low. For data analysis, matches (at the initial stage of the experiment) and differences (after the forming stage of the experiment) of the experimental and control group characteristics were determined according to Fisher's criterion. For this purpose, statistical hypotheses were formulated: the absence of differences between the levels of formation of the individual components of the system of professional competencies and the significance of differences between the levels of formation of selected components.

Analyzing the obtained results at the summarising stage of the experiment, it can be concluded that the levels of formation of professional competences of mathematics pre-service teachers in control and experimental groups coincide with the level of significance $\alpha$=0,05.

Comparing the levels of the formation of professional competencies in the control and experimental groups at the beginning of the formative stage and at the end of the experiment, one can observe an increase in the proportion of students with high and average levels of professional competence.

The cloud-based learning component with the use of CoCalc has undergone a quality estimation by the same method and the same set of indicators as the Maxima system learning component.

The resulting average value was calculated for every parameter among the technological ones (Fig. 2): "Ease of access" = 2.3, "Interface clarity" = 2.0, "Responsive-

ness" = 2.1, "Sustainability" = 2.3, "Support of Collaborative work" = 2.6, "Ease of Integration" = 2.0, "Usefulness" = 2.6, the total value was 2.27.

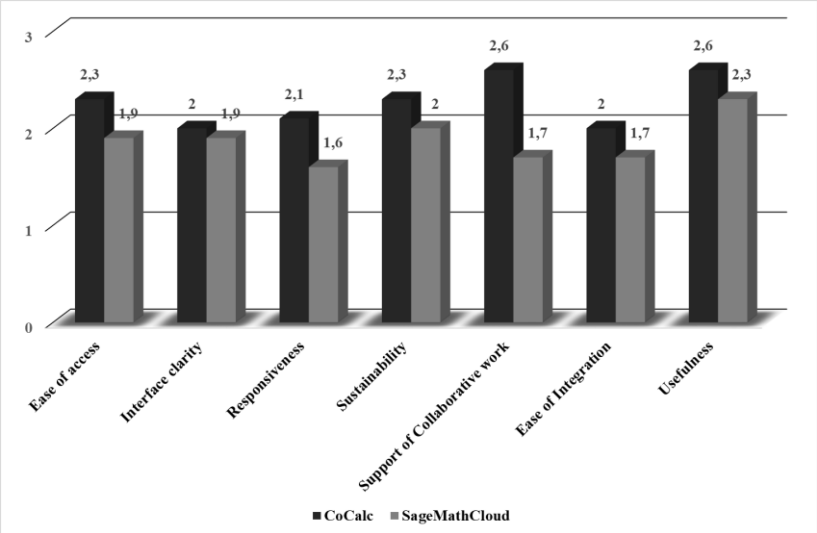


Fig. 1. The average value was calculated for every parameter among the technological indicators for CoCalc

The resulting average values for every psychological and pedagogical parameter was calculated as (Fig. 3): "Scientific clarity" = 2.5, "Accessibility" = 2.4, "Fostering the intellectual development" = 2.4, "Problem orientation" = 2.3, "Personalization" = 2.6, "Adaptability" = 2.4, "Methodical usefulness" = 2.6, "Professional orientation" = 2,5, "Feedback connection" = 2,7. The total value was 2.49 [9].

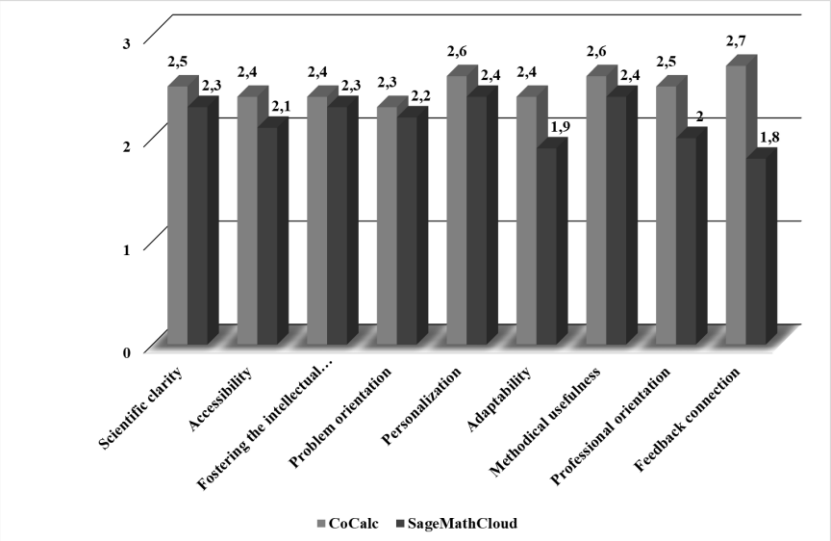


Fig. 2. The average values for every psychological and pedagogical parameter indicators for CoCalc

The resulted average criterion of EER quality K=2,38. This characterizes the resource quality as sufficient for further implementation and use. It shows that these components don't seem to have quite different differ scores by approach even being implemented for different tasks and disciplines. The CoCalc component still has rather high scores by "Support of Collaborative work" and by "Feedback connection" and "Personalization". This ensures an individual approach to learning with the use of this tool.

## 4 Conclusions and Discussion

The results of the study indicate certain movement in the development of new ways to create and use the software for educational purposes.

The use of mathematical packages to support the investigative approach to learning involves (I) understanding of the problems of the learning domain for proper use of SCM; (II) understanding the methodology of developing the algorithm from the mathematical statements and formation of the ability to apply this methodology; and (III) the ability to carry out the estimation of the algorithm `at run-time and memory requirements. In this case, SCM is to provide the tools for modelling and research of the domain objects in the learning process, to make experiments and approve the results.

The introduction and design of the cloud-based learning components into the process of training contributes to the growth of access to the best examples of electronic resources and services to support the research activities and person-oriented approach within the learning process. The use of these technologies adds and provides an op-

portunity to explore and develop an investigative approach to learning, which in turn leads to the development of new strategies and methodology of teaching of mathematics and computer science disciplines in educational universities. It brings the possibility to expand the investigative activity of students beyond the classroom, to provide the tools for modelling and research of the domain objects in the learning process, widening the spectrum of research activity due to the content fundamentality and interdisciplinary links establishment.

There are the tendencies of more active use of the cloud-based platforms for the software delivery, wider use of services virtualization, as well as their delivery as a service.

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