A model of application and learning of cloud technologies for future Computer Science teachers

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Abstract

Cloud technologies are emerging as a powerful tool for computer science education, as they offer various benefits such as scalability, accessibility, and collaboration. However, the training of future computer science teachers for the use of cloud technologies requires a systematic and comprehensive approach that covers both the theoretical and practical aspects of cloud computing. This paper presents a model of application and learning of cloud technologies in the process of training future computer science teachers. The model is based on the following principles: systematic, gradual, and continuous. The model consists of four components: target, content, operational, and effective. The model also defines three stages of using cloud technologies: as a means of organizing learning activities, as an object of study, and as a means of development. The paper also describes the design and implementation of a cloud-based learning environment (CBLE) that supports the proposed model. The CBLE is based on a hybrid cloud model that combines public and private cloud platforms. The CBLE also integrates cloud and traditional learning tools to provide a rich and diverse learning experience. The paper discusses the most suitable teaching methods for cloud technologies, such as classroom learning, interactive and e-learning, and practical methods. The paper provides several examples of how to apply the proposed model and methods in real learning scenarios. The paper evaluates the effectiveness of the proposed model and methods by conducting a pedagogical experiment. The paper uses various diagnostic tools, such as questionnaires, tests, laboratory and competency tasks, to measure the learning outcomes and satisfaction of the students. The paper performs a quantitative analysis of the experimental results and verifies their reliability using statistical methods.

Keywords

cloud technologies, computer science education, teacher training, cloud-based learning environment

1. Introduction

The digital transformation [1] of various sectors and domains of society has increased the demand for information and communication technologies (ICT) in education. ICT can provide access, flexibility, and innovation to the learning process, as well as enhance the skills and competencies of learners and educators [2, 3, 4, 5, 6, 7, 8]. One of the emerging ICT tools that has a great potential for education is cloud computing. Cloud computing is a remote computing model that allows users to access and use various resources and services over the Internet, such as storage, processing, software, platforms, etc. Cloud computing can offer various benefits for education, such as scalability, availability, and collaboration [9, 10, 11, 12, 13]. Cloud computing can enable learners and educators to work with educational materials regardless of their hardware, software, and geographical location [14, 15, 16, 17, 18]. Therefore, the study and use of cloud computing is essential for the curricula of colleges and universities, especially for the fields related to computer science and informatics.

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The aim of this paper is to design content and methods for teaching cloud computing to future computer science teachers.

The following objectives are set to achieve the aim of the research:

1. To analyze the current state of cloud computing education at leading foreign and Ukrainian universities.
2. To define the concept and principles of teaching cloud computing to future computer science teachers.
3. To propose content and methods for teaching cloud computing.
4. To conduct an experimental verification of the proposed content and methods.

The object of the study is the training process of computer science teachers.

The subject of the study is a model of teaching and learning cloud computing by future computer science teachers.

We used a combination of research methods: theoretical – analysis of scientific and technical literature, experience; generalization of experience of using cloud computing in education; empirical: observation, analysis, modeling method, methods of mathematical statistics.

2. Analysis of cloud computing learning experience

Cloud technology training is on the list of courses from leading US and European universities. Some of them are focused on the study of individual cloud platforms, while others involve the study of the theoretical foundations of cloud technologies. One major subject is administration training, while other students are learning to develop cloud applications.

For example, at Harvard University, students are offered a course in Fundamentals of Cloud Computing with Microsoft Azure. The content of this course covers the fundamental architecture and design patterns necessary to build highly available and scalable solutions using key Microsoft Azure platform as a service (PaaS) and server less offerings. The students learn fundamentals necessary to make a system ready for users, including always-up architecture and deployment strategies, rollback strategies, testing in production, monitoring, alerting, performance tuning, snapshot debugging in production, and system health analysis using application insights and analysis services [19].

Berkeley University offers a Cloud Computing: Systems course. In this course, teachers describe the technology trends that are enabling cloud computing, the architecture and the design of existing deployments, the services and the applications they offer, and the challenges that needs to be addressed to help cloud computing to reach its full potential. The format of this course will be a mix of lectures, seminar-style discussions, and student presentations. Students will be responsible for paper readings, and completing a hands-on project [20].

Cambridge University invites students to study cloud computing. This course aims to teach students the fundamentals of cloud computing covering topics such as virtualization, data centres, cloud resource management, cloud storage and popular cloud applications including batch and data stream processing. Emphasis is given on the different backend technologies to build and run efficient clouds and the way clouds are used by applications to realize computing on demand. The course includes practical tutorials on different cloud infrastructure technologies. Students assessed via a Cloud based coursework project [21].

At the University of Helsinki, students take the Cloud Computing Fundamentals: AWS course. Students learn how to use Amazon Web Services as a cloud computing platform. This course covers topics required for AWS Developer Associate certification. The course involves the creation and use of a trial account on AWS [22].

Yale University offers a Cloud Networking and Computing course. In this course, students will visit the critical technology trends and new challenges in cloud and data center designs for different trade-offs of performance, scalability, manageability, and cost in the networking layers and big data analytical frameworks. This course includes lectures and system programming projects [23].

Another approach is to study cloud technology in research labs and training centers. At MIT there is a laboratory called “Parallel & Distributed Operating Systems Group”. Teachers and students have conduct research in cloud systems, multi-core scalability, security, networking, mobile computing, language and compiler design, and systems architecture, taking a pragmatic approach: they build high-performance, reliable, and working systems [24].

The California State Polytechnic University is implementing a project to create a data center training facility through a partnership between the university and leading cloud platform developers (Microsoft, Avanade, Chef, Juniper). The Center is engaged in the deployment of a corporate cloud, through which practitioners will teach students the design, configuration, implementation and maintenance of cloud services and platforms [25].

Another promising way to acquire ICT competencies is to study with massive open online courses (MOOCs) [26, 27]. Students have the opportunity to acquire knowledge independently when they study in them. Universities can also integrate these courses into their own subject disciplines. Leading online platforms offer many cloud technology training courses.

For example, there is an Introduction to Cloud Infrastructure Technologies course on the EdX platform. It contains many chapters. These include basic: Virtualization, Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Containers and the latest such as Tools for Cloud Infrastructure, Internet of Things, How to Be Successful in the Cloud [28].

Coursera offers several courses to study: Essential Cloud Infrastructure: Foundation, Essential Cloud Infrastructure: Core Services, Elastic Cloud Infrastructure: Scaling and Automation, Google Cloud Platform Fundamentals: Core Infrastructure. These courses explore the Google Cloud Platform and AWS platforms [29]. In addition to high-quality educational content, the Courser platform provides access to the Google Cloud Platform and Amazon Web Services with the QuickLabs service. There, students can not only perform laboratory tasks, but also check the quality of their performance.

Udacity has developed a Become a Cloud Dev Ops Engineer nanodegree program. It provides learn to design and deploy infrastructure as code, build and monitor pipelines for different deployment strategies, and deploy scalable microservices using Kubernetes. At the end of the program, students will combine new skills by completing a capstone project [30].

The Computing Curricula 2017 document that is used in the development of IT education standards in the IT domain ITS-CCO (Cloud Computing) involves the study of such chapters [31].

ITS-CCO-01 Perspectives and impact;
ITS-CCO-02 Concepts and fundamentals;
ITS-CCO-03 Security and data considerations;
ITS-CCO-04 Using cloud computing applications;
ITS-CCO-05 Architecture;
ITS-CCO-06 Development in the cloud;
ITS-CCO-07 Cloud infrastructure and data.

Researchers and teachers from Ukrainian universities are also developing cloud computing courses. For example, the standards of the specialty “123 Computer Engineering” defined the ability of a specialist to analyze and design high-performance computer systems with different structural organization using the principles of parallel and distributed information processing [32]. The course “Cloud Technologies and Services” was developed in National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”. This course covers the following topics: Cloud technologies and services, Cloud security, Service Models, Google App Engine for Java platform, RESTful API build in Java. The Cloud Technologies course is taught at the Shevchenko National University’s Faculty of Information Technologies. The course covers basic information about the emergence, development and use of cloud computing technologies. Typologies of cloud deployment (private, public, hybrid, public, etc.), cloud computing service models (SaaS, PaaS, IaaS, etc.) are considered. The discipline provides an overview of the modern solutions of the leaders of the cloud computing market – Amazon, Microsoft and Google. The advantages and disadvantages of cloud computing models and their solutions are considered. To develop practical skills in the discipline, it is proposed to deploy transactional web applications in cloud environments, transfer ready-made solutions to them, learn how to administer them, and work with virtualization technologies [33].

3. Designing a cloud computing training model

Teaching future IT teachers the use of cloud technologies is also relevant. Usually, the pedagogical universities of Ukraine study courses focused on the use of cloud technologies in education. Most of them focus on the study of public clouds of Google Suite or Microsoft Office 365 [34, 35, 36].

In general, Ukrainian and European universities use cloud platforms to create their own cloud-based learning environment (CBLE). Vakaliuk [37, 38] is developing a methodology for using cloud computing to train informatics teachers and postgraduate students.

We interpret the concept of "the use of cloud technology" as an introduction to the practical work of a computer science teacher. Appropriate training of bachelors of computer science should be carried out continuously and in stages throughout the study period. Its effectiveness depends on the level of use of the tools in the learning process. Therefore, it is necessary to develop a model of organization of students' learning based on cloud technologies. As a result of the introduction of the proposed model, students develop ICT competencies for using distributed cloud resources for training and research.

The cloud-based student learning organization model changes the traditional reproductive approach to practically oriented learning. For its design we have analyzed similar models. They usually contain motivational, cognitive, activity, productive components [39, 40, 41].

They all transform the educational process from a system that operates on externally set standards to a self-evolving system. The main components of our model are shown in figure 1.

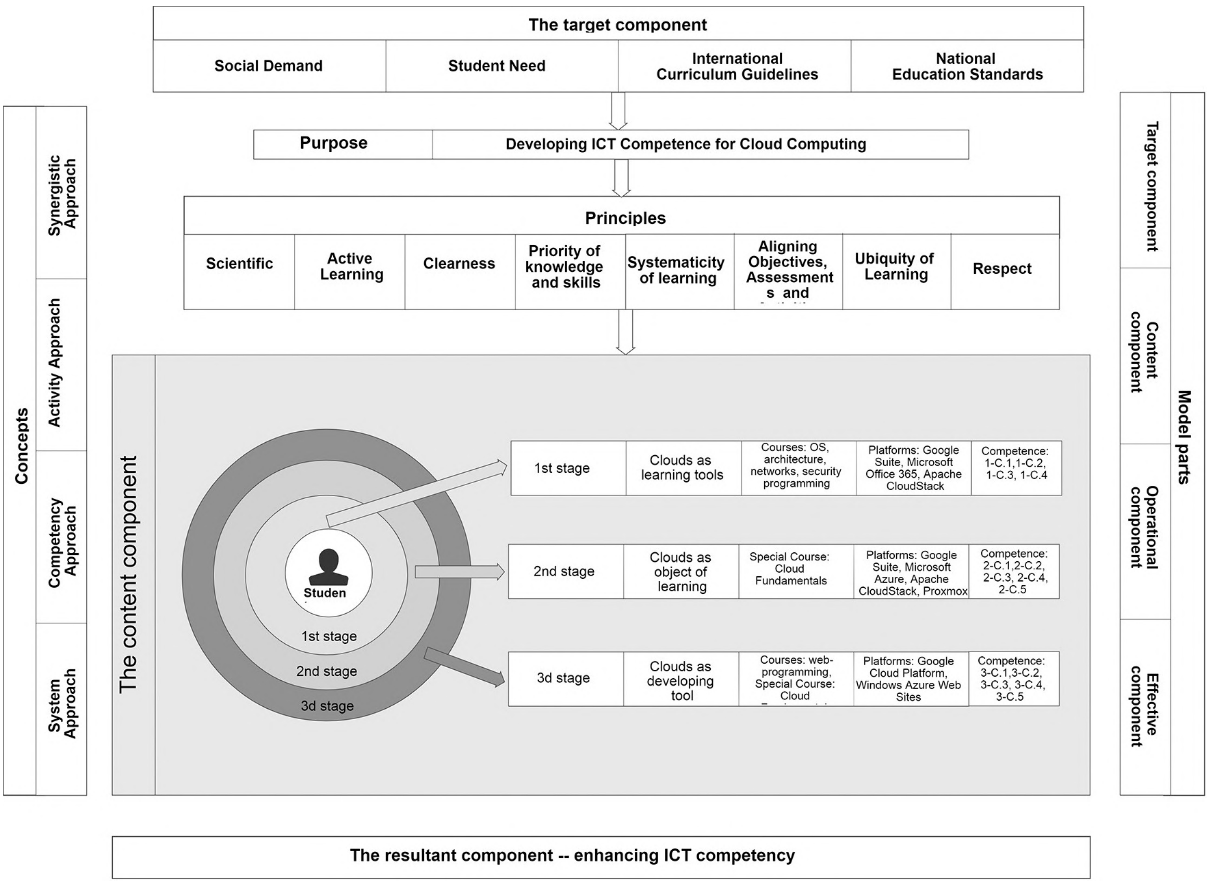

Figure 1: The model for learning cloud computing.

The target component of model provides the creation of conditions for the organization and support of joint educational and research work of students. It provides for the formation of cloud based learning environment of a university. Based on the previous analysis, we can claim that there is a social demand for a teacher who has competencies in the use of cloud technologies. Such a teacher should be able to organize the CBLE of school, to form the appropriate competence in students. In each of these three stages, we envision students using cloud computing at a different level of awareness. The purpose of this component is the goal setting of stage, on which the effectiveness of the whole process depends. The target component also determines the creation of conditions for the formation of personal capacity for future professional activity in the conditions of modern technological changes.

The purpose of training is implemented through methodological approaches such as:

- the competency approach allows to identify the content of ICT competencies in the use of cloud technologies, to improve the practical orientation of the learning process;
- the system approach allows to consider all components of the proposed model as a coherent system. A system approach requires designing the model as a set of interrelated elements. Integrative dependencies and interactions of these elements are also needed;
- the action approach focuses on the prioritization of active learning methods;
- synergistic approach considers the basic processes of student self-organization and interaction. Learning according to this approach is an unstable process. This instability complicates adaptation, cognitive operations, and overall activity.

The guiding principles of the methodology according to our model are the traditional principles of science, accessibility, continuity, systematicity and consistency, activity, clarity. Other principles of learning such as mobility, adaptability, flexibility, ubiquity are also important.

The content component of the model is aimed at developing both the key (digital, personal, social, educational) and subject competences of future computer science teachers.

At the center of the proposed model is a student. Accordingly, the competence structure defines the components by the stages of implementation. They correspond to the preparatory, activity, generalization stages of the use of cloud technologies. The study in the preparatory and activity stage should be done in the bachelor's degree. The generalization stage can be implemented as a master's program.

At the preparatory stage, cloud technology is a means of organizing educational and cognitive activity. The relevant components of subject competence are such as:

- ability to be guided by features of modern cloud technologies, to understand their functionality and to be used for basic educational tasks;
- ability to distinguish between features and characteristics of "traditional" Internet services, hosting web resources, running virtual private machines in cloud infra-structures;
- ability to determine the ways of using cloud technologies for the organization of training and research activities according to service models;
- ability to behave adequately and responsibly in a cloud environment, to demon-strate knowledge and understanding of the legal, ethical aspects of using cloud services and digital content;
- ability to actively and constantly explore new services, implement them in their activities, awareness of the role of cloud computing in the current stage of IT and education.

In the activity stage, cloud computing is the object of study. The relevant components of subject competence are such as:

- knowledge of basic concepts, deployment models and service models of cloud technologies, principles of operation and technology of server system virtualization, architecture and standards of distributed computing, and features of hard-ware and software solutions of modern data centers;
- ability to install, configure and maintain system, tool and application software of cloud platforms according to the basic service models;

- ability to evaluate and determine effective CBLE deployment decisions based on an analysis of the functional characteristics of cloud services and the needs of educational institutions;
- ability to design, deploy and integrate ready-made cloud platforms to improve the IT structure of the educational institution;
- ability to monitor, support and analyze the functioning of the CBLE.

At the generalization stage, cloud computing is a development tool for creating educational resources and learning tools. The relevant components of subject competence are as follows:

- ability to formulate requirements for quality assurance of software development for its functioning in the cloud applications;
- ability to evaluate and identify effective deployment solutions for CBLE based on a comparison of the technical and economic properties of cloud computing services, as well as for solutions based on private and hybrid cloud systems;
- ability to formulate ways to increase the efficiency of the use of cloud technologies in solving organizational educational and scientific tasks;
- ability to develop software for educational institutions in a cloud computing environment, test and debug relevant hardware and software;
- ability to project activities, work in a team to jointly solve educational and scientific tasks.

The technological component of the model defines the system of teaching methods. We consider appropriate methods of teaching cloud technologies such as:

- classrooms training (lectures, storytelling, presentations, group discussions, tutorials etc);
- interactive methods (quizzes, small group discussions, case studies, participant control, demonstrations etc);
- services, as well as for solutions based on private and hybrid cloud systems;
- e-learning (web-based training, web meetings, webinars, collaborative document preparation, work in CBLE);
- practical training methods (project, training).

In general, these methods aim at providing a blended learning methodology. Their application is possible during lectures, laboratory work, self-study trainings, individual and group consultations. We include the traditional means and components of CBLE in the training tools.

To provide group work and student feedback in each course, we use tools such as:

- emails and messengers;
- software for remote access to the objects of students in CBLE;
- module and final tests;
- Likert scale course feedback.

The resultant component of the model involves providing ubiquitous access to learning resources through standardized protocols, enhancing students' ICT competency, improving the quality of educational process organization and pedagogical research.

We consider it necessary to use public and private clouds as a teaching tool not only in the first stage, but also throughout the whole time of studying the bachelor of computer science. Such public clouds are G Suite and Microsoft Office 365. Their developers offer free subscriptions to educational institutions. Students and staff can get corporate accounts of these cloud platforms. The use of these platforms can be practiced in almost all courses of professional training of the future computer science teacher.

For example, a teacher can schedule study assignments, student work, online consultations using Calendar services. For training demonstrations, webinars can be effective cloud services such as Google Meet and Skype for Business and more.

Topical issues of using cloud technologies in training are their integration with each other and with other learning tools. Such integration should provide single authentication (Single Sign-On – SSO), content availability in various cloud services, access from mobile devices, and ability to monitor student activity.

Great technical and training capabilities are in the deployment of private academic cloud according to the IaaS model. We have deployed a similar cloud based on the Apache CloudStack platform. It combines the system resources of 4 servers. This allows you to run 20-50 virtual machines at a time. With Apache CloudStack's enhanced networking capabilities, we have integrated these computers into a large number of virtual local area networks (VLANs). To provide universal access to the virtual labs, 2 virtual private network (VPN) servers were set up. They work with different protocols. Therefore, students are able to work with these labs from any device that has Internet access. All these services have formed a cloud infrastructure that is integrated into the university's LAN. Such an academic cloud makes it possible to create "cloud laboratories". In our opinion, a cloud lab is a system where virtual ICT objects are generated through cloud computing and networking. Cloud labs are best used to teach basic computer science courses, such as computer architecture, operating systems, programming, computer networks, and more.

One of these laboratories (CL-OS) was deployed for training. Its purpose was the development of ICT competences, the education of the need for systematic updating of knowledge, the formation of project activity skills. To complete with the tasks, the students were supposed to have basic knowledge of the following disciplines: Operating Systems, Computer Architecture and Software. The main teaching methods in this training were group and project techniques. Students' educational projects were about practically important tasks, such as: recovery of destroyed data, increase of operating systems performance, error correction during loading, virus removal.

Students use G Suite and Microsoft Office 365 public clouds to discuss learning problems, create and edit shared documents (diagram, abstract, brochure, booklet, infographics). They acquire teamwork skills such as communication, teamwork and group leadership; formulation of tasks for yourself and colleagues, perform tasks in a timely manner [42].

Each of the group members was provided with a separate virtual machine. It had defects of one of the above types. Students were able to work on solving problems not only from any university computer, but also from their home PC. To train one group of students, an academic cloud provided 20–30 virtual machines (VMs).

Another cloud lab (CL-EVE-NET) was organized to study computer networks. We have integrated the Apache CloudStack and EVE-NG Community Edition platforms to deploy it. Nested Virtualization technology was used for this purpose. The EVE-NG platform makes it possible to emulate the operation of different nodes that are integrated in an internetwork. These nodes can be virtual machines running different operating systems. The integration of EVE-NG and Apache CloudStack platforms enables the use of full-featured network OS.

The integration of EVE-NG and Apache CloudStack platforms enables the use of full-featured network OS. They can be accessed via the EVE-NG platform web interface and through Telnet and VNC protocols. This lab uses both Apache CloudStack virtual networks and ENE-NG platforms. If the student configures the network connections correctly, access will also be available through the appropriate protocols.

We used the CL-EVE-NET lab to study basic computer network topics, such as: switching and bridging, network monitoring tools, basic and NAT routing; dynamic routing protocols; load-balancing Internet channel, policy base routing, data filter with firewall, network protocols and services (DHCP, ARP, DNS); virtual private network protocols [43].

This cloud lab allows you to bring together individual student networks. As a result, we get a internetwork of group. This approach ensures student collaboration and teamwork. An error with one of them can causes problems throughout the network. For the training of one group of students, an academic cloud provided the functioning of 20 "parent" VMs. They ran up to 10 nested virtual network devices (bridges, switches, routers, hosts).

The CL-ADM cloud lab has been deployed for the network administration course. In this course, we use both Windows and Linux. So, to study each topic, we create at least 2 virtual machines as servers and at least 2 VMs as clients.

The main topics of the course are:

- network administration of Windows and Linux servers (local users and groups, filesystems security, network shares, remote administration);
- domain administration (Active Directory, Samba, NIS);
- server application administration (Apache, ProFTPd, IIS, Postfix, Dovecot SQUID).

To train one group of students, an academic cloud provided 30–40 virtual machines. Training at the activity and generalization stages is carried out according to the special program "Cloud Technologies Fundamentals".

The course involves the study of: publicly available cloud platforms by recognized software development vendors (Google Inc., Microsoft), and open source software as the foundation for enterprise cloud.

The main topics of the special course are:

- public cloud platforms (G Suite and Microsoft Office 365);
- cloud platforms for private clouds (Apache CloudStack, Proxmox).

We used to study the G Suite and Microsoft Office 365 public platforms in the form of a Cloud Services to Every School project [44]. The objectives of the project were to design and deploy cloud services for secondary schools. The basics of the project concept were: absence of material costs for deployment and support of cloud services, voluntary nature of participation in the project. In collaboration with computer science teachers, students determined which services needed to be configured or migrated to the cloud. The problems of maintenance and support required a lot of time. Teachers had questions about administering, configuring, monitoring cloud services. We solved such problems by organizing face-to-face and distance seminars, workshops, also through the involvement of students in the support of deployed systems.

The results of the "Cloud Services to Every School" project is in line with the indicators of a cloud-based learning environment. They are: quality and accessibility of learning, adaptability, interactivity and mobility of ICT tools, unification of the school's IT infrastructure, ensuring its security.

We propose to study private clouds on the example of open platforms. We suggest exploring private clouds as an example of open platforms. Their advantages are open source, freeware, English documentation, the ability to deploy advanced cloud infrastructures. However, such platforms are usually not supported by the developer. Therefore, teaching students with such platforms often requires them to look for solutions to various problems. This approach requires modern hardware. Private clouds require servers that perform different functions. For deployment by students of such clouds it is necessary to use the group method. It is a division of tasks. Students can perform tasks together or individually such as:

- configuring the database server;
- cloud platform setup;
- installing hypervisors;
- creating virtual computers;
- distribution of system resources.

In the future, students change roles. Since at our university the special course "Fundamentals of Cloud Technologies" is studied in the master's program, we consider it appropriate to use a research approach. It is that the teacher formulates detailed technical requirements for the cloud. Students research and customize platforms to meet these requirements. The results of such research can be summarized by the method of comparative analysis. For example, one platform may have better performance for the production platform and another platform will perform more effectively as part of the CBLE.

Important in the ICT competency of the future computer science teacher is the possession of software development tools. Cloud services should be at the forefront of creating students' own educational information resources. The third stage of our model is dedicated to this task.Training can be based on this platform leader in software and cloud.

Microsoft has developed a Windows Azure Web Sites product that enables students to create new and host existing web applications in a secure cloud storage. Windows Azure Web Sites implements a Platform as a Service (PaaS) model. Therefore, students will be able to fully focus on the programming and direct development of their cloud projects.

Google also offers a similar Google Cloud Platform (GLP) cloud service. It allows you to create, test and deploy your own applications in the cloud. Students can learn how to create state-of-the-art web applications and mobile applications on the open Google App Engine cloud platform. It is a managed platform that completely abstracts the cloud infrastructure, which helps to focus training on development tasks.

Deployment of cloud laboratories is also appropriate for a full study of these systems. Unfortunately, Google has not yet provided academic grants to use GLP for Ukrainian universities. However, students are free to use their own accounts for one year. A similar situation with Microsoft products. It is necessary to get a Microsoft Azure Education Grant for effective learning.

We propose to use a comprehensive approach and project methodology in the process of studying these tools. The main requirements of applying the project methodology at this stage are as follows:

- identifying the main problem that the created project should solve;
- requirement for student creativity in project development;
- no restrictions on the tools and their functionality;
- the value of the expected result, that is, a cloud-based application must be developed and deployed;
- organization of joint activities of students;
- identification of pre-formed competencies for project creation;
- the project's focus on modern cloud and web technologies.

The third (generalization) stage of our methodology consists of several logical parts. They combine a relatively small amount of theoretical material. It's a good idea for a teacher to start learning about the Google Cloud Platform (GCP). The practical part involves setting up the environment and creating a project, configuring a cloud database. The next task is to log in and log in. After that, students should focus on project architecture and development of core functionality.

We invite students to develop a contact manager. Its main functionality is to enable an authorized user to create, view, edit and delete records. It also has the option of sending e-mails to selected contacts. This basic functionality is present in almost every modern web application. Students can use GCP cloud products such as Google App Engine standard environment, Google Cloud SQL, Google Cloud Datastore, Google Cloud Storage and Google Cloud Pub to develop it.

Application development in the Google Cloud Platform facilitates group form organization. The teacher can add new project participants and assign them specific roles to determine the degree of access. In this project, the teacher demonstrates GLP capabilities based on such programming tools as PHP and Node.js. Important issues for cloud-based application development are understanding:

- basic functionality of PHP and Node.js;
- basics of a modular, file and batch system;
- file management;
- use of the postal service;
- work with the MySQL database.

The next step is to introduce students to the Google Cloud Platform environment, the basics of App Engine, and the application deployment process. It is a good idea for the teacher to organize the development of the project in a private university cloud and then deploy it into a public cloud. It is also possible to develop the project only in a cloud environment. Both approaches include steps to develop a web application that will allow users to submit requests to the server.

After completing these tasks, students develop their own ICT competencies such as:

- creating a GCP project based on App Engine;
- writing a web server on Node.js;
- deploy code on App Engine and view the web application in real time;
- adding updates to an already deployed service.

After creating this application, students move on to expand its functionality through other GLP services. Further practical work focuses on developing students' own cloud applications. These can be an online study log, e-library, video hosting service, photo gallery etc. Their students perform in small groups of 2-3 people. They can offer their own themes for development. Upon completion, students present projects and share their experiences and achievements.

4. Testing the effectiveness of the author's methodology

We conducted a pedagogical experiment to verify the developed methodology. The study was conducted during 2016–2020. We investigated the development of ICT competence under the conditions of implementation of the proposed model. The aim of the study was to identify changes in the levels of ICT competence of students. According to the research of many scientists this competence contains basic theoretical knowledge, methods of practical activity, motivational relations and the ability to apply cloud technologies in the future [45, 46, 47]. They almost completely correspond to the structure of our model of application of cloud technologies. Let's look at each of these components.

The motivational (target) component contains motives, goals, needs for professional training, self-improvement, self-development by means of cloud technologies. It stimulates creativity in the professional activities of a computer science teacher. Accordingly, the student must develop a need for constant updating of his (her) own knowledge. The motivational component contains the motives for teaching, the focus on the development of students' personalities.

The content component of ICT competence of future computer science teachers provides free mastery of skills in working with digital objects. The level of development of the content component is determined by the completeness, depth, system of knowledge of computer and related sciences. It requires knowledge of the principles of cloud computing, its use for the design and development of educational resources. Knowledge of the security threats and limitations of these tools is also required.

Activity (operational) component involves the development of skills (including soft-skills) for the application of cloud technologies in future professional activities. These include the ability to establish interpersonal relationships in the educational environment, to choose the right style of communication in different situations. Basically, this component requires the skills and experience needed by future computer science teachers to solve problems using cloud technology. Advanced development of this component requires mastering and forming the readiness of future computer science teachers to develop and implement cloud computing in the educational process. The formation of appropriate skills should be determined by the professional needs of future computer science teachers.

The reflective (effective) component of ICT competence is determined by the attitude of students to their practical activities. It includes self-control, self-esteem, understanding of their own role in the team. Important for this component are the evaluation of the results of their activities, understanding the responsibility for its results, professional self-realization through the means of cloud technologies.

The study had ascertaining and search stages. The ascertaining stage corresponded to the first and second stages of the author's model. The study was conducted in the bachelor's course "Computer Networks". Since most of the components of the author's model are implemented at the generalization stage, we decided that the search stage should be performed in the process of learning a special course " Cloud Technologies Fundamentals".

At each stage of the experiment, the following data were processed:

- results of the questionnaire like course feedback, as data for studying the target component;
- grades for all course tests as data of the content component of the model;
- grades received by students for laboratory work as data of the operational component;
- assessments for a competency task as data of the effective component.

For statistical processing of these data, we used the methodology developed by Kuzminska [48, 49, 50, 51]. To ensure a sufficient sample size, we had to process the data for 4 years. We studied the changes and tried to identify differences in the data of each of the components of ICT competence. To ensure the homogeneity of the groups at both stages, the results of questionnaires and assessments of the same students were processed. There were a total of 196 students in these study periods. All data of the ascertainment and search stage are available by the following link https://drive.google.com/file/d/1n-lPQI-eGFMJiuwq_jI7BaWoM3aTUNK0.

Assessment in each of the courses was on a 100-point scale with a distribution such as:

- maximum 40 points for the test tasks of the course (content component);
- maximum 40 points for laboratory work (operational component);
- maximum 20 points for the performance of the competence task (effective component).

In addition to 20 points, the student could receive for answering the questionnaire, which gave an answer to the feedback about the course. To choose a statistical method, we took into account the following facts:

1. The data are quantitative; therefore, we can use numerical scales.
2. The data may not correspond to the normal distribution. Therefore, it is necessary to check this for each of the components of ICT competence at each stage of the study.
3. Samples of each year of study are independent.
4. There are 4 groups for comparison.

We performed data processing using the R language. First, we checked the data distribution of each component is normal for the ascertaining stage.

```
lillie.test(AscertainingStageData$Target)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Target
#D = 0.074284, p-value = 0.01045
lillie.test(AscertainingStageData$Content)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Content
#D = 0.056802, p-value = 0.1276
lillie.test(AscertainingStageData$Operational)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Operational
#D = 0.055232, p-value = 0.1531
lillie.test(AscertainingStageData$Effective)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Effective
#D = 0.085305, p-value = 0.001434
```

As can be seen from the code listing above, the data distributions of the content and the operational components are normal, and the target and effective are not. Therefore, a more powerful one-way ANOVA method for independent groups can be used to process the first two cases. Another pair of components should be processed using a non-parametric Kruskal–Wallis one-way analysis of variance. These methods allow to check whether the studied groups are homogeneous.

Additionally, for the ANOVA method, the homogeneity of variances in each distribution should be checked. We performed this using Leveneś test for homogeneity.

```
leveneTest(AscertainingStageData$Content\
~AscertainingStageData$Years,AscertainingStageData,center=mean)
#Levene's Test for Homogeneity of Variance (center = mean)
#       Df F value Pr(>F)
#group   3  0.2084 0.8905
#       192
leveneTest(AscertainingStageData$Operational\
~AscertainingStageData$Years,AscertainingStageData,center=mean)
#Levene's Test for Homogeneity of Variance (center = mean)
#       Df F value Pr(>F)
#group   3  1.6235 0.1853
#       192
```

As can be seen from the listing F value = 0.8905 and F value = 1.6235 (for content and operational components in accordance). These values are smaller for the critical value $F_{0.05}(3; 192) = 8.53$. The corresponding p-values (Pr = 0.8905 and Pr = 0.1853) are greater than the significance level ($\alpha = 0.05$). This is a reason to reject the null hypothesis about the difference of variances in the samples. Therefore, the ANOVA method can be used for the content and activity components.

Then the null and alternative hypotheses are as follows:

- H0 – there are differences between the groups at the ascertaining stage;
- H1 – there are no differences between the groups at the ascertaining stage;

The following code contains a test of these hypotheses.

```
summary(aov(Content~Years,data=AscertainingStageData))
#             Df Sum Sq Mean Sq F value Pr(>F)
#Years         3     57   18.96   0.822  0.483
#Residuals   192   4431   23.08
summary(aov(Operational~Years,data=AscertainingStageData))
#             Df Sum Sq Mean Sq F value Pr(>F)
#Years         3     57   19.04   0.751  0.523
#Residuals   192   4870   25.36
```

Thus, for both components we can reject the zero and accept the alternative hypothesis. Similar hypotheses can be formulated for the target and effective components. Here is a test of group homogeneity for these components using the Kruskal-Wallis one-way analysis of variance.

```
kruskal.test(Target~Years, data = AscertainingStageData)
#Kruskal-Wallis rank sum test
#data:  Target by Years
#Kruskal-Wallis chi-squared = 6.3968, df = 3, p-value = 0.09382
kruskal.test(Effective~Years, data = AscertainingStageData)
#Kruskal-Wallis rank sum test
#data:  Target by Effective
#Kruskal-Wallis chi-squared = 0.55391, df = 3, p-value = 0.9069
```

The test showed that we can accept an alternative hypothesis about the homogeneity of groups. The task of the search phase of the study was to identify differences between groups during the 2017-2020 years of the study. During this period, in each academic year, we introduced the some technical and methodological components of the mod-el such as:

- 2016–2017: deployed CL-OS laboratory;
- 2017–2018: the project "Cloud services in each school" was implemented;

- 2018–2019: deployed CL-EVE-NET and CL-ADM laboratories;
- 2019–2020: Coursera courses on Google Cloud Platform are included in the special course "Cloud Technologies Fundamentals".

Similar to the ascertainment stage, we analysed the results of the questionnaire, grades for tests, laboratory works and competence task.

The questionnaire for diagnosing the level of the motivational component contained 20 questions. For each positive answer to the questionnaire, the student received one point. Points for completing the questionnaire, grades from the course were obtained by students in a special course "Cloud Technology Fundamentals" in 2016-2020. Here are the questions.

1. I understand the importance of cloud technologies for the organization of educational activities.
2. I understand the importance of cloud technologies for the organization of design and research activities of students.
3. I understand the importance of cloud technologies for the organization of extracurricular activities of students.
4. I am aware that cloud technologies expand the opportunities for the development of students' ICT competence
5. I follow the emergence of new cloud services for education.
6. I am watching the emergence of new platforms for the deployment of private clouds.
7. I have studied cloud platforms in MOOCs.
8. I have the skills to develop cloud applications.
9. I can develop separate cloud services for CBLE school.
10. I know the benefits of cloud services as a means of supporting teacher self-development and self-improvement.
11. I understand that the use of cloud services has a positive impact on the quality of teaching and diversifies forms of learning.
12. I try to monitor the emergence of new resources and tools for cloud technology to improve their competence.
13. I realize that it is necessary for teachers to implement and disseminate new ideas about the use of cloud technologies.
14. I am aware of the advantages of cloud technologies and modern means of communication for cooperation between educational institutions.
15. I am aware of the benefits of cloud technology to reduce the cost of education.
16. I am interested in using cloud technologies to improve communication and increase the competitiveness of educational institutions.
17. I adhere to legal and ethical standards when using cloud services and digital content.
18. I participated in joint projects to develop an effective educational environment.
19. I have deployed cloud services for educational institutions.
20. I performed support of CBLE of school.

Diagnosis of the level of the analytical component of ICT competence of future computer science teachers was investigated by testing the ability to use the acquired knowledge and skills in non-standard situations. Students had to demonstrate the ability to perform reflective analysis and correction of their digital activities. We offered undergraduates to perform a competency task. They had to develop a long-term plan for the development of CBLE educational institution. The plan implementation algorithm was to contain a detailed description of each stage of CBLE deployment and use in the school.

1. CBLE design:
    - analysis of the state of the school's digital environment;

   - studying the specifics of the activities of teachers and students and determining their needs for the use of cloud services;
   - determining the functionality of cloud services;
   - identification of subjects for which it is not yet possible to implement the necessary functionality;
   - technical audit of the digital environment of damage, including hardware, software, personal devices, availability of Internet access;
   - finding out the financial capabilities of the educational institution.
2. Recommendations for implementation
   - informing teachers, students, parents about the structure and possibilities of using CBLE;
   - designing a security policy for the use of cloud services and notifying it to all participants in the educational process;
   - development and implementation of an algorithm for deploying cloud platforms;
   - technical and pedagogical support of activities in CBLE;
   - training of school staff, informing the administration about the development of digital technologies.
3. Development prospects
   - determining the scalability of the CBLE;
   - development of an action plan in case of breach of confidentiality of personal data;
   - support for modern standards, protocols, rules for updating all components of the environment;
   - participation in national and international educational projects.

Again, let's check the normality of the distribution of points obtained by students at the search stage. Here are the results of the Kolmogorov-Smirnov test:

- target component: D = 0.070342, p-value = 0.01958;
- content component: D = 0.060965, p-value = 0.07329;
- activity component: D = 0.062046, p-value = 0.06374;
- effective component: D = 0.10837, p-value = 0.000007515.

P-values for motivational and effective components again do not correspond to the normal distribution. P-values for the content and activity components are close to the critical value of 0.05, but still exceed it. Therefore, we will consider the obtained distributions to be normal. Let us check the homogeneity of their dispersions. Here is the result of running leveneTest:

- content component: F value= 0.9305, Pr(>F)= 0.427;
- activity component: F value= 0.5496, Pr(>F)= 0.649

Therefore, we can apply the One-way ANOVA test for the content and operational components. Here are the results of calling the corresponding function.

```
summary(aov(Content~Years,data=ResearchingStageData))
#              Df Sum Sq Mean Sq F value Pr(>F)
#Years          3    378   126.0   3.612 0.0143 *
#Residuals    192   6701    34.9
#Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

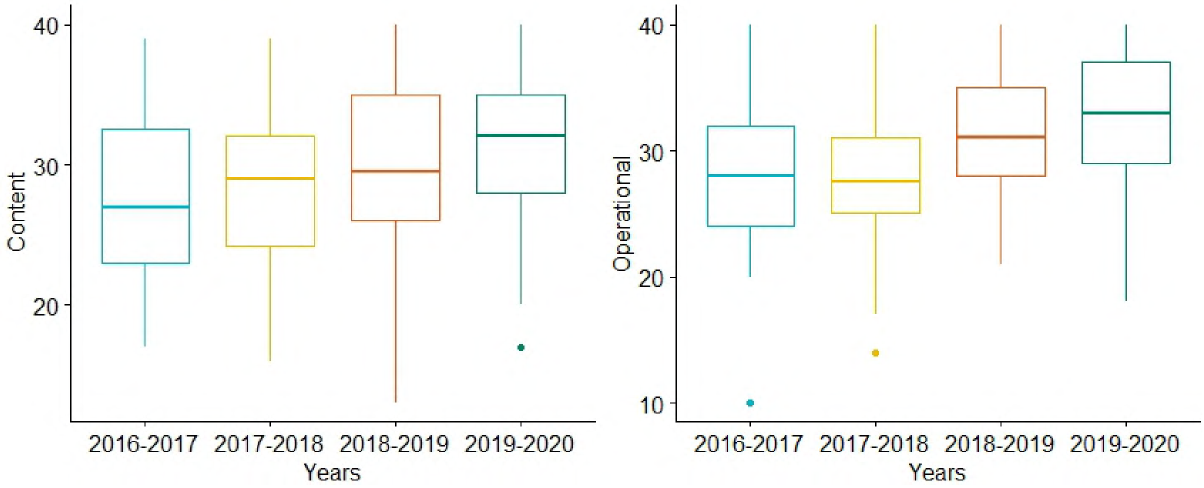

Figure 2: Range diagrams of average values of content and operational components

As can be seen from the listing, we have to accept the alternative hypothesis in both cases. That is, there are differences between groups. Figure 2 shows quantile scale diagrams. The dots on the chart show the emissions. In our case, such emissions are low grades of students who have very low grades from the course.

We can assume that the factor that caused these changes is the introduction of the author's methodology. To determinate a set of confidence intervals for the differences between the means of the factor's levels with the specified probability of coverage we have used Tukey's 'Honest Significant Difference' method for both components.

```
TukeyHSD(aov(Content~Years,data=ResearchingStageData))
#$Years                  diff        lwr       upr     p adj
#2017-2018-2016-2017 0.9925994 -2.1827991 4.167998 0.8496254
#2018-2019-2016-2017 2.3033885 -0.7508257 5.357603 0.2090704
#2019-2020-2016-2017 3.7281806  0.6022937 6.854068 0.0121774
#2018-2019-2017-2018 1.3107890 -1.7611233 4.382701 0.6863632
#2019-2020-2017-2018 2.7355812 -0.4076003 5.878763 0.1122965
#2019-2020-2018-2019 1.4247921 -1.5959128 4.445497 0.6133838
```

For the content component, the differences between the values of the 2016–2017 and 2019–2020 academic years are statistically significant changes.

```
TukeyHSD(aov(Operational~Years, data=ResearchingStageData))
#$Years                  diff        lwr       upr     p adj
#2017-2018-2016-2017 0.06336725 -2.9224371 3.049172 0.9999401
#2018-2019-2016-2017 3.45547675  0.5836212 6.327332 0.0111944
#2019-2020-2016-2017 4.33000434  1.3907555 7.269253 0.0010348
#2018-2019-2017-2018 3.39210950  0.5036125 6.280606 0.0140729
#2019-2020-2017-2018 4.26663709  1.3111262 7.222148 0.0013706
#2019-2020-2018-2019 0.87452759 -1.9658195 3.714875 0.8552859
```

From the above listing, we can conclude that almost all components of the model had the skills to create, deploy and use cloud technologies.

To assess the development of the target component, we use the Kruskal-Wallis test. Here are its results:

- Target by Years Kruskal-Wallis chi-squared = 7.0967, df = 3, p-value = 0.06888;

From the obtained test data, we can still accept the null hypothesis that there are no statistically significant differences between the groups. Therefore, we cannot draw a reasonable conclusion about the impact of our model on the development of the motivational component of ICT competence.

For the reflex component, the results of the Kruskal-Wallis test are as follows:

- Effective by Years Kruskal-Wallis chi-squared = 18.66, df = 3, p-value = 0.0003213;

In this case, we accept an alternative hypothesis about the existence of differences between groups of students. In order to make multiple comparisons between groups, possibly with a correction to control the experiment wise error rate we have performed Dunn's Kruskal-Wallis test. Here are its results:

```
PT = dunnTest(Effective~Years,data = ResearchingStageData)
PT
#          Comparison           Z      P.unadj       P.adj
#1 2016-2017 - 2017-2018  0.08638957 0.9311567356 0.931156736
#2 2016-2017 - 2018-2019 -1.70307343 0.0885543273 0.177108655
#3 2017-2018 - 2018-2019 -1.78256141 0.0746577266 0.223973180
#4 2016-2017 - 2019-2020 -3.66052102 0.0002517029 0.001258514
#5 2017-2018 - 2019-2020 -3.72765494 0.0001932697 0.001159618
#6 2018-2019 - 2019-2020 -2.06601565 0.0388270019 0.155308008
```

The results of this test show that there are differences between 2016-2017 – 2019-2020 and 2016-2017 – 2019-2020 pairs of years. Therefore, we can conclude that participation in a real project had a positive impact on students' integrated under-standing of the role of cloud technologies in the digitalization of the school learning process.

5. Conclusion

The use of cloud computing in the training of future computer science teachers is a relevant and important issue that requires further research. The training of cloud computing should be systematic, gradual, and continuous throughout the student's study period. We have proposed a model of teaching and learning cloud computing for future computer science teachers, which consists of four components: target, content, operational, and effective. The content component is implemented in three stages:

1. Cloud technology as a means of education.
2. Cloud computing as an object of study.
3. Cloud computing as a development tool.

The first and second stages should be conducted in the bachelor's degree, while the third stage can be offered as a master's program.

The current level of cloud computing development makes the project method a suitable and effective way of teaching and learning cloud computing. Participation in the proposed projects helps students develop their skills of independent and responsible work with cloud technologies, as well as their awareness of the role and potential of cloud computing.

Our model combines face-to-face and online learning, which allows teachers to leverage the advantages of the cloud-based learning environment (CBLE). The CBLE is based on a hybrid cloud model that integrates public and private cloud platforms, as well as cloud and traditional learning tools.

According to the results of the experiment, our hypothesis of a positive impact of the designed CBLE on the development of ICT competence of future computer science teachers was confirmed. The experiment showed significant improvements in the students' integrated understanding and practical skills of cloud computing.

The qualitative changes in the dynamics of development of ICT competence components of students using our model confirmed the effectiveness of our methodology.

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