

The Experience of Using Cloud Labs in Teaching Linux Operating System

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Abstract

The paper is devoted to the problem of studying the Linux operating system (OS) by future computer science teachers. The authors have developed a learning tool -- the cloud lab (CL-OS). Based on an analysis of related research, they concluded that a cloud lab is a system that uses cloud computing technology to provide the desired user interface to access computing resources. The authors have systematized some experience of using mass open online courses (MOOC) and remote access laboratories. They made assumptions about the possibility and necessity of creating cloud laboratories in universities and colleges. This article described the experience of deploying an authors' cloud laboratory. It is based on integrating the NDG Linux Essentials course from Cisco NetAcad and the Apache Cloud-Stack cloud platform. The authors have analyzed the specifics of training under the conditions of using their cloud laboratory. In particular, some limitations and problems of students' work under the conditions of the real educational process (both face-to-face and online) were identified. A pedagogical experiment was conducted to confirm the effectiveness of the author's approaches. Its results were verified using statistical methods.

Keywords

Cloud Lab, Cisco Network Academy, Future Computer Science Teacher, Operating Systems, Linux

1. Introduction

1.1. The problem statement

The course of operating systems was and remains basic in the training of IT professionals and computer science teachers. Relevant ICT competencies are provided in many international and national training standards. Even though this course is basic for many years, there are still problems in organizing its study. One of the most important ones is the provision of access to various operating systems and the organization of independent students' work [1]. This was confirmed by numerous lock-downs during the Covid-19 pandemic.

1.2. Analysis of recent research and publications

Many researchers now suggest the use of virtualization technologies in the teaching of computer science [2],[3]. However, virtualization alone does not always provide convenient ubiquitous access for students to computer resources. Remote labs also use virtualization. Some of them have been developed to study STEM-disciplines [4],[5],[6].

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In general, they offer the sharing of study objects published on one computer by several students. When it comes to computer science, such labs are not reliable and scalable enough. Therefore, their educational content is usually taken from MOOCs. For example, in the study [7], the remote electronics laboratory in the MOOC environment was expanded.

The advantages of MOOC include the ability to study at a convenient time, opportunity to compare teaching styles and materials of different courses, the experience of participation in discussion, self and mutual evaluation; improving listening, reading and written English skills, reflection on one's own pedagogical activities in the light of new ideas, digital creativity and collaboration with other participants [8]. Studies show that MOOCs, given their scale and reusability, serve as a cost-effective way to offer higher education [9]. MOOCs can also be a way to address the growing income gaps affecting access to higher education. They all use a cloud-based approach to providing open access to knowledge. However, this is not enough now. This is because today such systems must ensure adaptability in learning. Ukrainian researchers note that adaptive cloud-based learning systems will become the driving force behind the development of new pedagogy, new strategies for personalizing education, and expanding opportunities for active learning [10]. Currently, many platforms have been developed and are successfully operating, implementing the concept of MOOC. Among them are recognized world leaders EdX, Coursera, Udacity. The application of these courses in the process of training future IT specialists and computer science teachers requires theoretical development and experimental testing of the relevant methodological model. Its main goal is for students to become part of the social, technical system of education, where the teacher is not the most important centre but is a node of the general network [11].

Cisco is developing an ideology for providing mass access to computer and network technology knowledge within the Cisco Network Academy. They offer both professional and commercial courses. However, there are basic ones that are available to a wide range of users and educational institutions.

The purpose of the article is to describe and systematize the experience of using the cloud laboratory as a learning tool in the university course of operating systems.

2. Experience in using cloud labs

Today, cloud technology is an effective model for providing access to computing resources. Many researchers suggest their use as a training tool for training future IT professionals [12], [13], [14], [15], [16]}.

Based on analyzing some research, we can conclude that the cloud laboratory is an information system in which network virtual ICT objects are formed. Such labs use a special user interface (first of all based on the web), which allows working with the user interface of OS in any case. It should not depend on whether the network is running on the virtual machine (VM) or not. Such objects in cloud labs are an integral part of logical network infrastructure with a flexible architecture that, according to its structure and time, corresponds to some personal needs of a user [17]. But only cloud computing is not enough to effectively use such labs in education. It needs to integrate into each cloud lab high-quality learning content, add tools to ensure individualization and adaptability of learning [18].

Gillet and Li [19] have explored the concept of cloud laboratories as common spaces that integrate applications. Researchers are also studying the problem of integrating MOOC into the learning environment. They note that cloud labs can enable the implementation of MOOCs, allowing teachers or students to collect and monitor the use of openly available learning resources.

Our research performed in the Joint laboratory of the Institute of Information Technologies and Learning Tools of NAES of Ukraine, Ternopil Volodymyr Hnatiuk National Pedagogical University (Ukraine). In this study, such integration was performed for a lab to study the Linux operating system. In general, our author's course "Operating Systems" is designed for 2 semesters. In the first, students study Windows, and in the second - Linux.

To deploy the CL-OS cloud lab, we adapted the NDG Linux Essentials course from the Cisco Networking Academy [20]. Its teaching does not require prior training and accreditation of the teacher. The course is available in English only. In our opinion, this fact had more positive than negative consequences. Therefore, during the introduction of the cloud laboratory in the course, we discussed and agreed with the students some provisions:

- The use of applications (plugins) to translate the course is allowed.
- Students must learn concepts from operating systems in both languages (Ukrainian and English).
- Additional tasks are offered by the teacher in English, but they are discussed in native (Ukrainian) for students.
- Communication with the teacher in the language of the student's choice. This fact does not affect the evaluation.

It is possible to localize and adapt the content of this course at the university's LMS University. However, we did not use this method because it infringes the copyright of the course developers. Also in this case students can't receive a certificate of completion of the course.

Let's list the main topics and their objectives from the course "NDG Linux Essentials", which we offered for students to study:

- Operating Systems: Linux Evolution and Popular Operating Systems. Choosing an Operating System.
- Working in Linux: Linux Evolution and Popular Operating Systems. Major Open Source Applications. ICT Skills and Working in Linux.
- Open Source Software and Licensing: Open Source Initiative (OSI). Open source licensing. Open source philosophy. Free Software Foundation (FSF).
- Command Line Skills: Basic shell. Command line syntax. Variables Quoting.
- Getting Help: Info and Man pages.
- Navigating the Filesystem: Files, directories. Hidden files and directories. Home directories. Absolute and relative paths.
- Managing Files and Directories. Files and directories. Case sensitivity. Simple globbing.
- Archiving and Compression.
- Working With Text: Command line pipes. I/O redirection. Basic Regular Expressions.
- Basic Scripting: Basic shell scripting. Awareness of common text editors.
- Where Data is Stored: Programs and configuration. Processes. Memory addresses. System messaging. Logging.

We did not offer students modules such as Network Configuration, System and User Security, Creating Users and Groups, Ownership and Permissions. Their content is provided for study in other courses. However, the content of these modules is present in the final exam. As a result, there is a problem for students to receive a certificate of completion of this course. We invite students to take this test later or to study the relevant material on their own.

The original NDG Linux Essentials course does not involve learning the graphical user interface. This is probably due to a large number of implementations. However, we added an appropriate module and asked students to do a comparative analysis of several GUIs for Linux.

In this course, we did not conduct classical lectures. Instead, they talked to students in mini-lectures. And it doesn't matter if it was lectures in the audience or online through cloud services. In these mini-lectures, we explained the basic concepts of the module, as well as repeated, systematized and established links with the concepts that were mastered by students later. For example, in the Operating Systems module, we mentioned basic concepts such as the operating system, its functions and components. Also here we made a comparison with Windows. In the module "Where Data is Stored" in mini-lectures, we systematized the concepts of processes, flows, multitasking planning strategies, RAM management technologies.

The concept of the cloud laboratory corresponds to the modern paradigm of cloud computing. It provides ubiquitous on-demand access to a shared pool of configured and distributed computing resources. The architecture of such laboratory, shown in Figure 1.

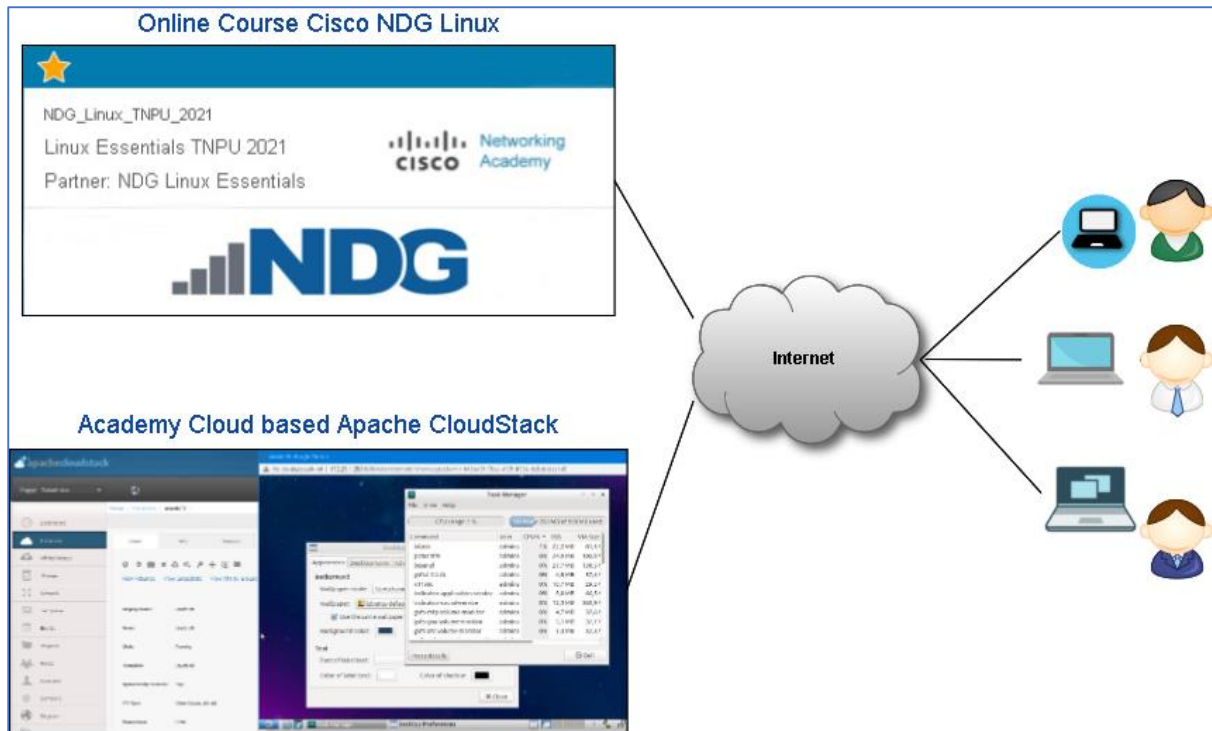


Figure 1: The architecture of the laboratory CL-OS.

Our laboratory corresponds to the cloud concept: it is fully automated, inexpensive and scalable in design; Apache CloudStack cloud platform architecture provides simultaneous work of students with Linux VM from 50 to 100 students. The maximum number of VMs will be in the case of the command-line mode of VMs running. If you need to work with a graphical interface, the number of VM will be approximately 2 times less.

The laboratory is built according to the IaaS model. Its infrastructure allows you to combine, route and filter network traffic such as

- Local network of the university.
- Virtual local area networks of cloud infrastructure.
- Virtual private networks through which students access the university's cloud resources.

All this makes it possible to ensure the unified work of users with VMs using remote access.

Each module of the course contains theoretical material. It contains the introduction, the objectives of the module and its main terms. The module material is structured in small blocks. This allows you to improve the quality of assimilation of the material. Laboratory works include tasks and a "sandbox". It is a virtual machine command terminal with Ubuntu Linux. Students perform tasks of laboratory work there (see Figure `).

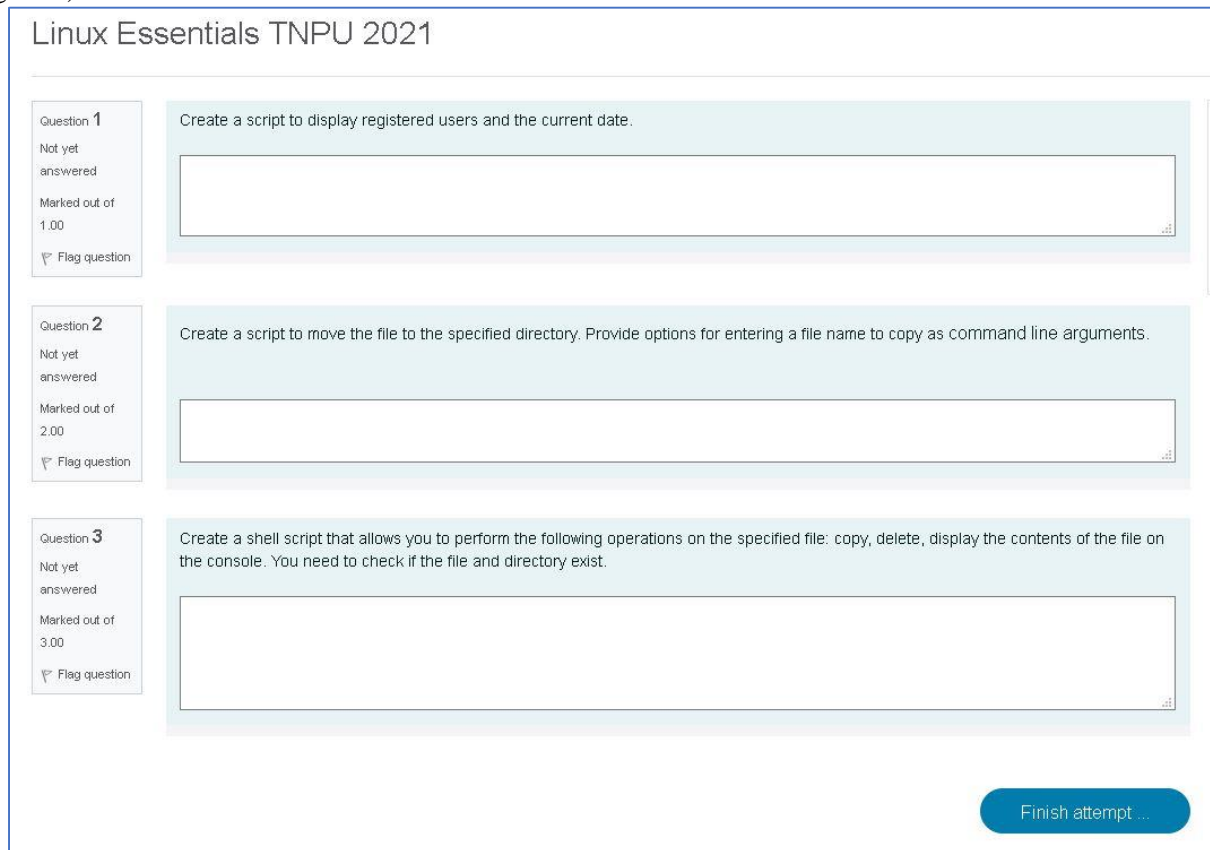
```

NDG Linux Essentials - Lab 5: Command Line Skills
Share Help
>_ Ubuntu PC
top - 07:37:54 up 7 days, 10:20, 1 user, load average: 0.11, 0.09, 0.09
Tasks: 8 total, 1 running, 7 sleeping, 0 stopped, 0 zombie
%Cpu(s): 1.0 us, 0.1 sy, 0.0 ni, 98.8 id, 0.0 wa, 0.0 hi, 0.0 si, 0.0 st
KiB Mem : 65968600 total, 52639736 free, 5441472 used, 7887392 buff/cache
KiB Swap: 2097148 total, 2097148 free, 0 used, 60207892 avail Mem

  PID USER      PR  NI   VIRT   RES   SHR  S  %CPU  %MEM    TIME+  COMMAND
    1 root        20   0   4384    712    652  S   0.0   0.0   0:00.03  init
    7 root        20   0   78640  3680   3128  S   0.0   0.0   0:00.01  login
   10 syslog    20   0 191332  3748   3244  S   0.0   0.0   0:00.34  rsyslogd
   14 root        20   0  28364  2696   2432  S   0.0   0.0   0:00.00  cron
   16 root        20   0  72308  3252   2512  S   0.0   0.0   0:00.00  sshd
   26 bind       20   0 217056 18260   7120  S   0.0   0.0   0:00.02  named
   47 sysadmin  20   0  19224  4016   2872  S   0.0   0.0   0:00.01  bash
   60 sysadmin  20   0  38712  3136   2688  R   0.0   0.0   0:00.00  top
  
```

Figure 2: The Linux command-line UI sandbox.

We created our own tasks. This was done because the proposed laboratory work in the original course does not contain tasks for independent work. We tried to make these tasks different in complexity, such as the first, second and third level. Tasks are also selected randomly from a bank of quizzes. If such tasks were created in sufficient numbers (in our case about 200), it ensured that the student completed his own block of tasks. We analyzed the capabilities of LMS MOODLE. Cisco Networking Academy currently runs courses based on this system. A good option is to use the "random task" plugin. However, it is not available at the Cisco Networking Academy. Therefore, we used the "test" module. All his tasks were divided by levels of complexity and took the form of an essay (see Figure 3).



The screenshot shows a Moodle quiz interface for 'Linux Essentials TNP 2021'. It contains three questions, each with a text input field for an answer. Question 1 asks to create a script to display registered users and the current date. Question 2 asks to create a script to move a file to a specified directory with command-line arguments. Question 3 asks to create a shell script to perform copy, delete, and display operations on a file, with a requirement to check if the file and directory exist. A 'Finish attempt' button is visible at the bottom right.

Figure 3: Example of an independent task on laboratory work "Working with Text".

This required a personal examination of the tasks by the teacher. This approach has created a lot of work for the teacher. It involves reviewing each essay and communicating with the student. We think this is especially true for online learning during a lockdown.

The Google Meet cloud service from the Google Workspace for education package was used to organize the training. All laboratory work was recorded and shared. Assessment of learning outcomes was carried out through personal communication between the teacher and the student in a separate room. Chapters tests were also evaluated.

To ensure the performance of laboratory tasks, the cloud laboratory contained virtual machines from the "sandbox" or those that run on the cloud platform Apache CloudStack. We used this method to increase the effectiveness of training in such cases.

- Network access. Web browser access is truly unified and in line with the ideology of cloud computing. However, it is not comfortable enough to work with. For example, students often have problems copying and pasting commands. Therefore, we pre-configured VM templates to work with two commonly accepted SSH and VNC protocols. The first of them provides the ability to work in the terminal to execute commands, and the second provides remote access to the graphical interface of KDE, GNOME, Unity.
- Multiuser mode. The built-in sandbox does not allow the user to open multiple terminals. This does not allow the student to fully understand that Linux is a multi-user and multi-tasking OS. For example, when performing laboratory work in module 13 "Where Data is

Stored", they had problems performing tasks such as putting processes in the background, finding and changing the priority of the process, forcibly terminating the process.

- Long-term data storage. The built-in sandbox does not allow you to save data. This creates significant inconvenience for students. For example, in the work "Basic Scripting" in their VM-"sandboxes" store scripts. This requires them to be permanently saved on local computers and copied to the VM.
- The graphical interface and various distributions. Although Linux has many GUIs, we have been working on developing invariant skills to work with these interfaces. Therefore, we have prepared several distributions with graphical interfaces KDE, Gnome, Unity and offered students to perform the same tasks in them.
- Interaction and joint work. In our cloud lab implementation, multiple students can work with the same VM at the same time. This is possible thanks to network access. Another way is to use so-called VM projects from the CloudStack infrastructure, which are available to multiple users.

The VPN service was used to provide remote access to the Apache CloudStack platform. To ensure the security of data transmission in VPN tunnels, we have configured an L2TP server. It was integrated with the radius server. This provided unified authentication based on the Active Directory LDAP directory. Unfortunately, we still haven't managed unified user authentication on the Cisco Networking Academy sites. This would integrate the OS interface with Apache CloudStack directly into the course pages.

3. An experiment to test the effectiveness of using a cloud laboratory

To test the effectiveness of the implementation of our CL-OS laboratory, we experimented. According to our methodology, there were four groups with a total of 54 students. They passed the course for one semester. The experiment was performed in 3 stages. At each of them, students received grades such as

- for all topics about Windows (previous semester)
- for the intermediate exam in the course "Cisco. NDG Linux Essentials".
- for the final exam in the author's edition.

The last fact is that there are modules on computer networks that will be studied by students later in other courses.

We complied with the requirements for the organization of the experiment: training during both semesters was conducted by the same teacher, test tasks had approximately the same structure (contained the same number of theoretical and practical tasks of different complexity). The test results from all 3 stages were transformed into a 100-point scale. They can be downloaded by the link https://drive.google.com/file/d/1m_Bq30MeYVvK1r-uNI-efdaYU5RICMPdm/

As can be seen from the table, it contains columns such as student ID and the names of each stage of the experiment (t1-t3). We performed statistical processing of experimental data in the R-Studio environment according to the method proposed by Olena Kuzminska [21]. To choose the right method, we checked the normality of the distribution of points at each stage. For this purpose, Lilliefors (Kolmogorov-Smirnov) test for normality from nortest library was used. The results for each stage are as follow:

- $p_1 = 0.088$;
- $p_2 = 0.539$;
- $p_3 = 0.093$.

That is, all distributions can be considered normal. We examined the scores obtained at each of the three stages as related samples. In this case, anova for repeated measurements is used to find out the differences between the samples. Here are the hypotheses for the chosen statistical method.

- H_0 is the null hypothesis about the equality of the average values of the scores at each stage of the experiment.
- H_1 is an alternative hypothesis about a significant difference in the mean values.

Using the `pwr.anova.test` function, we made sure that the sample size was sufficient. The following code snippet was used to test whether the null alternative hypothesis holds.

```
Student <- as.factor(Student)
Stage <- as.factor(Stage)
summary(aov(Rating ~ Stage + Error(Student/Stage)))
```

The results of the test are as follow:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Stage	2	2924	1461.9	32.17	1.2e-11 ***
Residuals	106	4816	45.4		

That is, we can accept the alternative hypothesis. That is, the CL-OS cloud lab is the factor that caused these changes. If you group the scores of students on the ECTS scale as shown in Figure 4, you can see an increase in the number of high rates in the 2nd and 3rd stages.

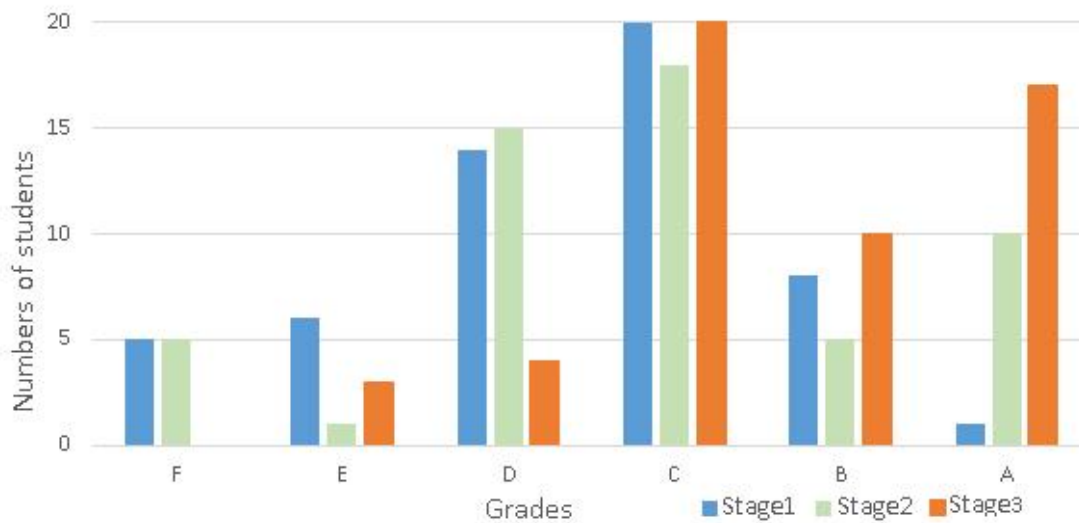


Figure 4: Distribution of grades at each stage according to the ECTS scale.

We used the Tukey "Honest Significant Difference" to test which stages of the study had a significant difference in averages. The results of this test are as follows.

Stage	diff	lwr	upr	p adj
2-1	3.333333	-1.751728	8.418395	0.2701706
3-1	10.203704	5.118642	15.288765	0.0000136
3-2	6.870370	1.785309	11.955432	0.0047549

Thus, we can state that there are statistical differences between the estimates of the 1st and 3rd stages of measurement. Regarding the first and second stages, perhaps the reason for this result is the novelty of the training material. However, most students have not previously worked on Linux and its command interface.

4. Conclusions

Developed by us cloud laboratory has the main characteristics that are inherent in cloud computing technologies such as

- a web browser is all you need to access learning resources and virtual machines,
- on-demand service - the student can immediately receive system resources (turn on, restart the virtual machine) without prior request,
- online access to the laboratory via the Internet from anywhere in the
- world. To work with CL-OS laboratory from the Internet, each student can use a VPN connection,

- scalability, which provides the ability to change the number of calculated resources without significant changes in the operation of operating systems.

The proposed cloud laboratory can be effectively used in both face-to-face and distance learning. The presented approach implements the basic ideas of the hybrid learning model. For example, in face-to-face training, the teacher explains and demonstrates the study material offline. In addition, students can perform individual tasks from any device. The teacher has the opportunity to help and control their work.

The results of the pedagogical experiment confirmed the hypotheses about the influence of the cloud laboratory on improving the efficiency of studying Linux by future computer science teachers. It can be stated that it is expedient to deploy such laboratories in universities and colleges.

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