Using native virtualization technologies for teaching IP telephony to future IT specialists

Liliia V. Pavlenko, Maksym P. Pavlenko

Berdyansk State Pedagogical University, 4 Schmidta Str., Berdyansk, 71100, Ukraine

Abstract
This paper explores the use of virtualization technologies for teaching IP telephony to future IT specialists. It defines the requirements for students' professional training in this field and identifies the components of a network training laboratory for IP telephony. It also analyzes the modern approaches to virtualization technologies and their advantages for learning IP telephony. The paper proposes native virtualization as a suitable solution for creating a virtual training laboratory using VirtualBox software. It reports the results of a pedagogical experiment that confirmed the effectiveness of the developed virtual laboratory and repository of virtual hosts for teaching IP telephony. The paper highlights the benefits of virtual machines for student mobility and remote learning, especially during the pandemic and war.

Keywords
IP telephony, virtualization technologies, VirtualBox, network training laboratory, professional training

1. Introduction

The education of future IT specialists requires the use of modern learning technologies, including information technologies. The rapid development and improvement of hardware and software platforms pose a challenge for higher education institutions to keep up with the current requirements and demands of society in the field of information technology [1].

This challenge is especially evident in the teaching of the discipline of "IP telephony in computer networks" to future IT specialists. To prepare them effectively, they need to acquire the following knowledge and skills:

- installing, operating and maintaining various operating systems in network environments, both local and global;
- installing, configuring, operating and maintaining IP telephony software in network environments, both local and global.

One of the possible solutions to this challenge is the introduction of virtualization technology in the educational process.

However, the implementation and application of virtualization technology in the education of future IT professionals face many organizational, methodological and technical problems. There is no unified concept or approach to its use. The development and application of virtualization technology in different domains of computer science have been studied by Khomenko et al. [2], Lunsford [3], Osadchyi et al. [4], Ray and Srivastava [5], Stefanek [6], Yan [7], Yuan and Cross [8], Yuan et al. [9].

The use of virtualization in the teaching of information technology has been investigated by Chamberlin et al. [10], Barrionuevo et al. [11], Khomenko et al. [2], Oleksiuk and Oleksiuk [12], Popel et al. [13], Segeč et al. [14], Seidametova et al. [15], Soler [16], Vakaliuk [17], Vakaliuk et al. [18], Vlasenko et al. [19], Yuan et al. [20, 21].

AREdu 2023: 6th International Workshop on Augmented Reality in Education, May 17, 2023, Kryvyi Rih, Ukraine
liliya.pavlenko@meta.ua (L. V. Pavlenko); pavlenko.2277@gmail.com (M. P. Pavlenko)
https://bdpu.org/en/faculties/fmkto/structure-fmkto/kaf-ktun/composition-ktun/pavlenkolv/ (L. V. Pavlenko); https://bdpu.org/en/faculties/fmkto/structure-fmkto/kaf-ktun/composition-ktun/pavlenko-2/ (M. P. Pavlenko)
0000-0001-7823-7399 (L. V. Pavlenko); 0000-0003-0091-696X (M. P. Pavlenko)

The use of virtualization in the training IP telephony to future IT specialists has been explored by Abubakr et al. [22], Kaul and Jain [23], Moravcik and Kontsek [24], Rendon Schneir and Plückebaum [25], Setiawan et al. [26].

The *aim* of this paper is to analyze the existing virtualization technologies and their potential for teaching IP telephony in computer networks to future IT specialists.

2. Reasoning for choosing a virtualization system for learning IP telephony

Training of future IT specialists in accordance with the state standard of higher education involves the formation of a number of professional competencies [27, 28, 29, 30, 31, 32]: the ability to use operating and intelligent systems in solving practical problems, taking into account the protection of information in computer systems and networks; ability to use programming languages and software engineering in solving problems and tasks of social and professional nature; ability to analyze, debug, use and develop human-machine interaction based on computer architecture and organization.

They are formed during the study of a number of professional-oriented disciplines, one of which is "IP telephony in computer networks".

In accordance with the purpose of the study, we will consider virtualization technologies and identify prospects for their application to train future IT professionals in IP telephony in computer networks.

The study of "IP telephony in computer networks" uses two Asterisk servers based on Debian or Ubuntu Linux and at least two client personal computers with Windows operating systems and IP telephony software installed as a network training laboratory. This hardware and software are necessary to model the network interaction of IP telephony clients and servers using SIP, IAX2, H.323 protocols. One of the areas of a network laboratory development and implementation for the study of IP telephony is the application of virtualization.

The concept of virtualization appeared in the 1970s. It was understood as the transfer of physical resources of a computer into a virtual one with the help of specialized software, abstract layers allow creating several virtual machines on one physical machine, each virtual machine being able to work with its operating system [33].

Virtualization, as a concept, is used for two technologies that are fundamentally different: resource virtualization and platform virtualization. Resource virtualization, in contrast to platform virtualization, has a broader meaning and combines a large number of different approaches aimed at improving the usability of users with information systems in general. In our study, we will build on the concept of platform virtualization, as related technologies are evolving and are effective in achieving the goals of training future IT professionals.

Platform virtualization is understood as the creation of software systems based on existing hardware and software complexes. A system that provides hardware resources and software is called a host, and the systems it simulates are called guest systems. There are several types of virtualization platforms, each of which has its own approach to the concept of "virtualization". They are mainly determined by how full the hardware simulation [34].

We will consider virtualization with full emulation. This approach completely virtualizes all the hardware while keeping the guest operating system unchanged [35]. This allows you to simulate different hardware architectures. For example, you can run virtual machines with guest systems for x86 processors on platforms with a different architecture. Examples of software for complete simulation are: Bochs, Pearpc and QEMU.

The main disadvantage of this approach is that the simulated hardware significantly slows down the performance of the guest system, which makes interaction with it very inconvenient. Therefore, such products should not be used as a basis for developing a virtual training laboratory to study "IP telephony in computer networks" discipline.

Let's consider paravirtualization as a basis for the development of a virtual training laboratory for the study of the "IP telephony in computer networks" discipline. While using paravirtualization, the hardware is not simulated, a special software interface (API) is used to interact with the guest operating system at the level of RAM pages.

This approach requires modification of the guest system code. A significant number of hardware and software developers have doubts about the prospects of this approach to virtualization [36], because today all decisions of hardware manufacturers regarding virtualization are aimed at systems with native virtualization. In addition, it should be noted the difficulty of deploying new instances of virtual machines for users. Therefore, the use of paravirtualization software in learning IP telephony in computer networks is impractical. Examples of paravirtualization are Xen, L4, TRANGO, WindRiver and XtratuMhypervisors.

We will consider partial (native) virtualization in the context of our study. In this case, only the required amount of hardware to run an isolated virtual machine is simulated [37]. This approach allows you to run guest operating systems designed only for the same architecture as the host.

In this way, multiple samples of guest systems can be run simultaneously, allowing you to simulate a computer network with IP telephony servers and clients on a single personal computer. This type of virtualization can significantly increase the speed of guest systems compared to full emulation and it is widely used today.

Beside this, the distribution of already established guest systems among users is quite simple and possible only on the basis of copying files. Disadvantages of this type of virtualization include the dependence of virtual machines on the architecture of the hardware platform, but for the "IP telephony in computer networks" discipline we use operating systems and software for x86 architecture. Examples of products for native virtualization: VMware Workstation, Virtualbox, Parallels Workstation and others, including server solutions (VMware Server, Microsoft Virtual Server, VMware ESX Server, VirtualIron and Microsoft Hyper V).

We will consider the virtualization of the operating system level and identify opportunities for its use to train future IT professionals in IP telephony in computer networks. The guest system, in this case, shares the use of one kernel of the host operating system with other guest systems [7]. The virtual machine provides an environment for applications that run in isolation. This type of virtualization is used in the organization of virtual hosting systems, when you need to support multiple virtual client servers within one instance of the kernel.

This technology allows you to isolate each virtual system and deprive them of the ability to influence each other. Examples of operating system layer virtualization include: iCoreVirtualAccounts, Linux-VServer, LXC, OpenVZ, ParallelsVirtuozzoContainers, FreeBSDJail and sysjail.

We will consider virtualization of the application level. This type of virtualization involves the creation of separate containers for software isolation. The container includes all the necessary elements for the correct operation of the software: registry files, configuration files, user and system objects. As a result, the user receives an application that does not require installation on a similar platform.

Transferring the software to another computer will create a virtual environment for it, and the virtualization program resolves conflicts between the software and the operating system and other applications. Examples of such an approach are: Thinstall, Altiris, Trigence, Microsoft ApplicationVirtualization (App-V). Using application-level virtualization to train IP telephony to future IT professionals is impractical, due to the need to create a computer network model with separate servers and workstations rather than software.

So, we can affirm that one of the best solutions for the introduction of virtualization in the methodology of teaching IP telephony discipline in the computer networks will be the technology of native virtualization. This can be explained with the ability to use virtual machines in independent and classroom work of students, easy export of ready-made solutions and the ability to create a complex network infrastructure among downloaded virtual machines.

Let's consider the problem of choosing the specific software for native virtualization in order to use it to teach IP telephony in more detail. Let's analyze the possibility of using one of the three popular solutions for virtualization in the workplace: VMware Workstation, Parallels Workstation and VirtualBox.

VMware company is one of the best known in the high technology industry. It develops effective software in the field of virtualization. Their implementation of server software is widely used in virtual data centers and personal computers in business and industry.

VMware has two types of desktop software: VMware Workstation and VMwarePlayer. Every virtual client supports and works with virtual machines flawlessly. But the Workstation option has more features, namely: support for two monitors, integration of the Unity interface, and most importantly the ability to create virtual machines. The Player version only allows you to run and execute previously created virtual machines.

Teaching IP telephony in computer networks involves students creating their own virtual machines, so VMwarePlayer software cannot be used due to the existing restrictions on creating new virtual machines.

VMware Workstation functionality allows you to use it on computers running Windows and Linux operating systems. The wizard for installing and debugging new virtual machines is simple and intuitive, and the default settings for specific operating systems are selected quite well. This allows students not to spend a lot of study time mastering software management skills.

Unity virtual interface integration allows you to include virtual machine elements directly into the host operating system interface. That is, icons and windows from a Windows virtual machine will work with icons and windows from the Ubuntu operating system. However, the use of Unity leads to a significant slowdown of virtual machines and complicates their use.

Parallels company is developing a software product for PC virtualization – Parallels Workstation. It solves the main task of virtualization – the simultaneous launch of multiple operating systems on a single computer running Windows or Linux. This product uses features designed for professionals in the field of local and online applications, software testing professionals and web designers. It can also be widely used for educational purposes.

During Parallels Workstation development the requirements for the product by IT specialists were considered. This software can work with more than 25 major operating systems – both 32-bit and 64-bit. High performance of Parallels Workstation is compatible with Intel VT-x2 virtualization technology and the use of a hypervisor.

However, owing to Controlled Native Execution (CNE) technology, Parallels Workstation allows you to run guest operating systems on older computers whose processors do not have hardware support for virtualization. Parallels Workstation's professional user interface offers many options for creating and configuring virtual machines, but an untrained professional will not be able to quickly create and install a virtual machine, making it difficult to use Parallels Workstation to teach IP telephony in computer networks.

VirtualBox is open source software, i.e. free of charge. Individual commercial functional elements are downloaded in the form of plug-ins. VirtualBox combines features of solutions for both servers and workstations. The first includes technologies of "balloon" dynamic redistribution and reduplication of RAM in a virtual machine on 64-bit hosts, iSCSI support, GUI-free mode and an efficient method of remote access to virtual machines through a shared RDP-server (VRDP, VirtualBox Remote Display Protocol). The second is high-quality support for USB equipment, including USB 2.0, as well as 2D and 3D acceleration in virtual machines due to the resources of the host graphics adapter.

VirtualBox can provide virtualization in a purely software mode or by using hardware support in modern processors. It uses disassembly of guest OS code and a number of other techniques, combining them.

While creating new virtual machines, the developers of VirtualBox managed to protect their users from possible problems and the need to understand the technical details. In most cases, it is sufficient to agree with the default settings, adjusting only the necessary and obvious of them, say, the amount of RAM.

In this case, the program will to some extent control the correctness of the selected parameters and, if necessary, make corrections or issue appropriate warnings. It is no coincidence that all the most subtle settings and actions can be performed exclusively from the command line, which, of course, requires the user to have some understanding of what is happening. These features are very convenient to use while creating and debugging virtual machines when learning IP telephony in computer networks.

As one can see from table VirtualBox software supports multiple operating systems, allows you to connect up to 36 network adapters to a virtual machine and is distributed free of charge. All this points to the benefits of using VirtualBox as the main virtualization tool in the development of a network lab for training future IT professionals in IP telephony in computer networks.

Table 1
Features of VMware Workstation, Parallels Workstation and Virtualbox.

Feature	VMware Workstation	Parallels Workstation	VirtualBox
Supported host operational systems	Windows, Linux, Mac OS X	Windows, Linux, MacOS X	Windows, Windows Server, Linux, Mac OS X, Solaris, OpenSolaris, FreeBSD
Guest operational systems	DOS, Windows, Linux, FreeBSD, Solaris	DOS, Windows, Linux, OS/2	DOS, Windows, Windows Server, Linux, OpenBSD, FreeBSD, OS/2, Solaris, OpenSolaris, others
Network adapters	before 4	before 5	before 36
Virtual disk controllers	IDE or SCSI	IDE (before 4)	IDE or SATA (before 32 disks) or SCSI
USB support	Yes	Yes	Yes
3D acceleration	Limited	No	Yes (OpenGL)
Remote access to the virtual machine	Limited	No	Built-in RDP server
Remote USB support	No	No	Yes
Shared folders	Yes	Yes	Yes
Open software	No	No	Yes
License cost	Workstation for Windows/Linux approximately $199	Workstation for Windows/Linux - $49.99	Free of charge

3. Repository of virtual machines for teaching IP telephony

The content of the discipline “IP telephony in computer networks” involves a series of laboratory work:

1. Installing Asterisk and Free PBX.
2. Basic configuration of the IP telephony server.
3. Configure Asterisk to work with the SIP protocol.
4. Configure the Asterisk dial plan.
5. Calls management in Asterisk.
6. Voice services and menus in Asterisk.
7. Integration of Asterisk into the organization corporate network.

Two servers and several clients are required to perform laboratory work. Virtual hosts in the VirtualBox environment are created as servers. One core, 512 MB of RAM and 10 Gb on the virtual

HDD are allocated for the Virtual Server. The client virtual hosts configuration has 1 Gb of RAM and Windows 7 Home and LinuxMint 18 operating systems.

The server virtual hosts have the Ubuntu 18.04 and AsteriskFreePBX 15 operating systems installed.

Client virtual hosts have software for IP telephony using the SIP protocol – LinphoneDesktop 4 (https://www.linphone.org). This program is open and free. It works in Windows, Linux and MacOS operating systems.

Two IP telephony servers are required to simulate the interaction of server hosts on the Internet. Client hosts are used to test IP telephony features on users' devices (figure 1).

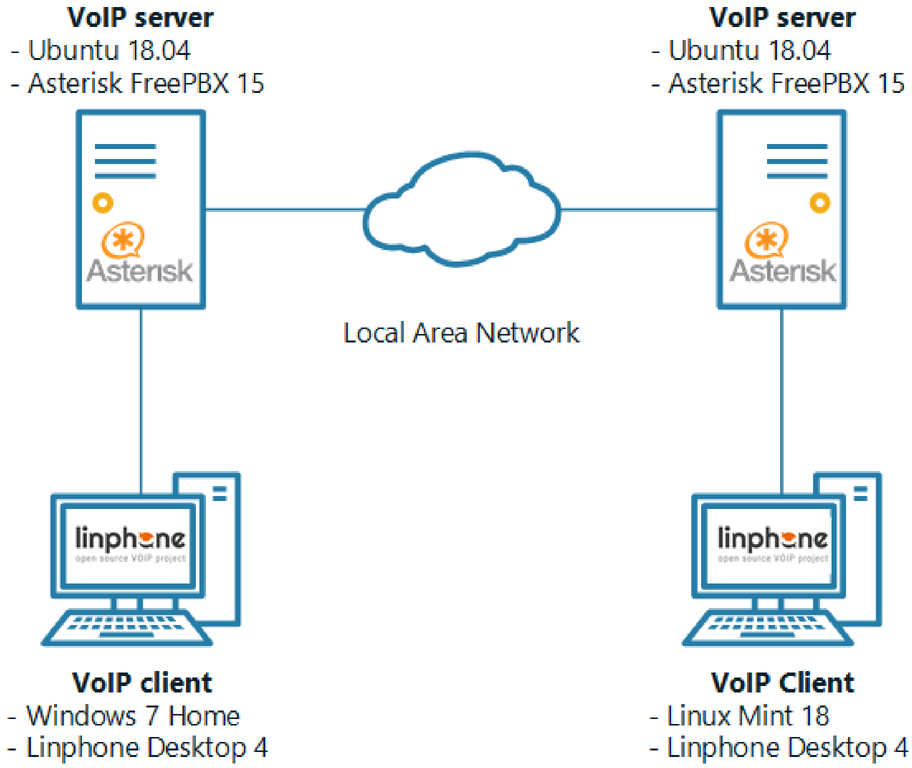

Figure 1: Virtual laboratory of IP telephony.

A set of virtual machines for application in VirtualBox has been prepared for each laboratory work. The developed virtual machines are placed on the internal server of Berdyansk State Pedagogical University. Students can download the required images of virtual machines to perform lab work at any time.

4. The results of the experimental research of virtualization technologies introduction in training of IP telephony

The introduction of virtualization technologies in the training of future IT specialists involves conducting experimental research. The purpose of the pedagogical experiment is to test the research hypothesis: the use of virtualization technologies to teach IP telephony to future IT professionals will help increase the level of knowledge acquisition and skills in the field of IP telephony and computer networks.

The offered methodological approach to the application of virtualization technologies for training IP telephony of future IT specialists should provide the solution of the following tasks:

- software application for virtualization of servers and clients of IP telephony;
- systematic solution of debugging software problems and IP telephony protocols with the use of native virtualization;
- training time increasing to work with a network laboratory for the study of IP telephony.

Students of Berdyansk State Pedagogical University studying in the specialties 015 Professional Education (Computer Technologies) and 015 Professional Education (Digital Technologies) were involved in the experiment. The plan of the experiment provided for the creation of control and experimental groups. The experimental group consisted of 35 students and the control group of 39 students accordingly. Selection for control and experimental groups was carried out immediately before the study of "IP telephony in computer networks" discipline.

Classes in the control group were conducted using a hardware network laboratory. The method of conducting classes in such a laboratory provided for the organization of students' access to the equipment according to the schedule.

The organization of the educational process in the experimental group involved the application of virtualization technologies using the VirtualBox software and the developed repository of virtual machines. Virtual machines were organized according to the educational tasks of the discipline and were configured to perform specific practical tasks for setting up network software for IP telephony.

The success of the pedagogical experiment was insured by the use of such research methods that guarantee a reliable result. The following methods of pedagogical research were chosen: pedagogical observation at all stages of the experiment, tests, analysis of laboratory work, analysis of test results in the experimental and control groups.

The experiment studied the dynamics of the knowledge acquisition level and skills development in the field of IP telephony technologies and computer networks. The experimental technique involved the use of virtualization technologies at all stages of learning:

- while studying new material, as a system for demonstrating the features of setting up technologies and protocols of IP telephony;
- in consolidating the studied material, as a mean of developing skills in the field of IP telephony;
- in independent work, as an environment for the implementation of a professionally-oriented project to configure IP telephony servers in the corporate network of the enterprise.

Two tests were conducted to test the effectiveness of the virtualization technology implementation. The first test was conducted at the beginning of the study of the discipline. The purpose of this test was to determine the readiness of students of control and experimental groups to study IP telephony and covered the issues of installation, configuration and administration of server operating systems and networks. The test consisted of fourteen basic level tasks and three advanced tasks.

The second test was conducted at the end of the study of "IP telephony in computer networks" discipline. It consisted of ten basic tasks and five advanced tasks.

A comparison of students' knowledge acquisition level and skills development in the field of network technology and administration of server operating systems at the beginning of learning "IP telephony in computer networks" discipline revealed similarities in the levels of knowledge acquisition and skills of students in control and experimental groups.

A comparison of the results obtained after studying the discipline "IP telephony in computer networks" revealed differences between the levels of knowledge acquisition and skills formation in the control and experimental groups.

Table 2 shows the results of control works at the beginning and at the end of the experiment in the control and experimental groups.

Comparative analysis of tests results allows us to conclude about the positive dynamics of the knowledge acquisition level and skills in the field of IP telephony in both groups. In the experimental group the dynamics is more pronounced: a 14% increase in the share of students who coped with the task from 75 to 90% of the total (5% in the control group), a 19% decrease in the share of students who coped with tasks from 50 to 75% of the total number of tasks (in the control group increased by 5%) (figure 2).

The share of students in the experimental group who coped with more than 50% of advanced tasks increased by 40% (in the control group the indicator hasn't changed). Statistical parameters of the experimental results are shown in table 3.

Table 2
The results of tests hold at the begging and at the end of the experiment.

	Before the experiment		After the experiment	
	Control group	Experimental group	Control group	Experimental group
Whole results of the test				
Managed with the test (%): including	90	94	90	94
• more than 90% from the whole work volume	5	9	10	14
• from 75 to 90% from the whole work volume	13	20	13	34
• from 50 to 75% from the whole work volume	62	65	67	46
• less than 50% from the whole work volume	20	6	10	6
Tasks of advanced level				
A part of students that have done:				
• more than 50% of the tasks of advanced level	5	14	5	54
• less than 50% of the tasks of advanced level	13	17	26	29
• those, who haven't reached the tasks of advanced level	82	79	69	17

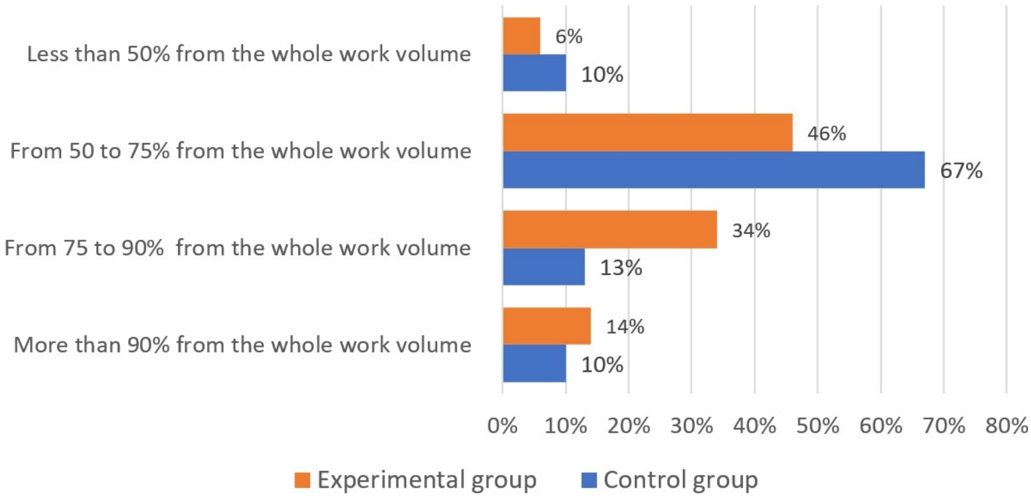

Figure 2: The results of test hold at the end of the experiment.

Analysis of the data in table 3 allows us to say about the positive dynamics in both groups, but in the experimental group the dynamics is more pronounced: the average score for the control work increased by 1.57 (in the control group by 0.85). In the Experimental Group, the median sample increased by 2 points. In the control group, the median increased by only 1 point.

Let's test the hypothesis of a normal sample distribution. We use Pearson's criterion for this. We formulate working hypotheses:

- H_0 – the empirical distribution is a subject to the normal distribution law,
- H_1 – the empirical distribution is a subject to another distribution law.

Table 3
Statistical parameters of knowledge acquisition levels and skills formation in IP telephony in the control and experimental groups before and after the experiment.

Parameters	Control group before the experiment started	Control group after the held experiment	Experimental group before the experiment started	Experimental group after the held experiment
Sample volume	39	39	35	35
Average	12.85	13.46	13.70	15.03
Median	12	13	13	15

The results of the hypothesis test are shown in table 4.

Table 4
The results of testing the hypothesis of the sample distribution normality.

Group	Before the experiment		
Control group	$\chi^2_{empirical}$ 16.64	$\chi^2_{critical}$ 19.68	Accepted hypothesis H_0
Experimental group	$\chi^2_{empirical}$ 17.60	$\chi^2_{critical}$ 18.30	Accepted hypothesis H_0
	After the experiment		
Control group	$\chi^2_{empirical}$ 12.56	$\chi^2_{critical}$ 18.30	Accepted hypothesis H_0
Experimental group	$\chi^2_{empirical}$ 9.96	$\chi^2_{critical}$ 19.68	Accepted hypothesis H_0

Since it was found that all distributions obey the normal law, Student's criterion was chosen for further comparison of the samples (table 5). This will help to determine whether the level of knowledge acquisition and skills development in the field of IP telephony differ in the control and experimental groups. For this purpose working hypotheses were formulated:

- H_0 – levels of knowledge acquisition and skills development in the field of IP telephony of the two groups do not differ.
- H_1 – levels of knowledge acquisition and skills in the field of IP telephony in the two groups are different.

Table 5
The results of statistical test of hypothesis.

Before the experiment		
$t_{empirical}$ 0.8	$t_{critical}$ 1.99	Accepted hypothesis H_0
After the experiment		
$t_{empirical}$ 2.3	$t_{critical}$ 1.99	Accepted hypothesis H_1

The obtained results indicate that at the level of significance $\alpha = 0.05$ the levels of knowledge acquisition and skills formation in the control and experimental group before the experiment coincide and differ after the experiment.

So, the results of the pedagogical experiment indicate that the research hypothesis has been confirmed, namely, the use of virtualization technologies to teach IP telephony to future IT specialists helps to increase the level of knowledge acquisition and skills in the field of IP telephony and computer networks.

5. Conclusions

Virtualization technologies were originally designed for software development and testing purposes. However, they can also be used for educational purposes in the field of information technology.

This paper has shown the benefits of using virtualization in the educational process with VirtualBox, in the discipline of "IP telephony in computer networks":

- the ability to run different operating systems on the same host and enable network interaction among them for implementing IP telephony service;
- the ability to isolate and control potentially risky actions of the operator or software products. In this case, the virtual machine acts as a safe and flexible laboratory platform for the student;
- the ability to create various hardware configurations for simulating network interaction scenarios in the study of IP telephony in computer networks. The students can use predefined hardware configurations to test the performance of Asterisk servers under different conditions. They can also perform various practical experiments with software and hardware components;
- the ability to create repositories of ready-to-use virtual machines with guest operating systems configured according to the specific laboratory tasks. The students can use these virtual machines for learning and research purposes in the field of IP telephony. The recovery of the system from a saved state is fast and easy in case of any damage;
- the ability to run multiple virtual machines connected to a virtual network on a single physical computer. This feature provides significant capabilities for creating virtual network models among multiple systems on a single host;
- the ability to increase student mobility by exporting and moving virtual machines to another computer. The students can start their virtual machines immediately on any host. This is a significant advantage of virtualization during the COVID-19 pandemic, when students have to study remotely. Each student can have his or her own virtual laboratory;
- the ability to enhance control over backups, snapshots and recovery of virtual machines in case of failures.

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