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Alleviate the contending issues in network operating system courses: Psychomotor and troubleshooting skill development with Raspberry Pi

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Abstract: Despite the growing popularity of network operating system courses in vocational high schools, issues have been raised regarding the lack of appropriate computer hardware specifications and the limited use of real networking devices. The media that have been used in teaching network operating systems have been based on virtualization-based simulation. However, such virtualization does not expose students to real hardware. This results in less than optimal hands-on activities and students' psychomotor abilities. Consequently, alternative authentic media are needed to accommodate practical learning and improve psychomotor skills. The aim of this study is to explore the implementation of a single-board microcomputer in learning network operating systems. The Raspberry Pi was chosen as it can replace the role of a non-simulation PC. The choice of Raspberry Pi was also based on the fact that in Indonesia it is still rare to find its implementation for teaching and learning activities in vocational high school, so it is necessary to introduce the device to students. The operating system used by the Raspberry Pi is similar to Ubuntu, which is one of the network operating systems that must be mastered by vocational IT students. The research made a comparison between the two learning media as employed by two groups of students in different classes, one using virtualization-based simulation and the other using the Raspberry Pi. Based on the results, it is concluded that

the use of the Raspberry Pi is more effective than that of virtualization-based simulation in improving students' psychomotor and troubleshooting skills.

Keywords: network operating system, Raspberry Pi, simulation, vocational high school

1 Introduction

Mastering a network operating system is one of the learning outcomes at Indonesian vocational high schools which have an information technology expertise programme. Students must be able to operate various network operating systems that are commonly used in the business and industrial world. Currently, the most popular operating systems used in business are open-source ones, such as Ubuntu, Debian, and Centos, among others [1].

It is a challenge for vocational high schools to produce graduates who are skilled in mastering network operating systems. In the related course practice activities at schools, network facilities and server infrastructure are the major problems faced. To learn an open-source-based network operating system, a minimum set of computers with mid-end specifications and groups of basic network devices is required [2]. The minimum infrastructure for computer specifications costs at least 100 million IDR for the practical activities of 20 students. Based on limited observation, several solutions have been implemented. Some of these include procuring an assembled modular personal computer at a lower price, or creating a dual-boot mechanism on an existing PC to run a different operating system. But these approaches have not solved the problem.

The first solution, building an assembled PC, faces problems when the specifications are not able to not keep up with the minimum requirements of next-generation operating systems and there are difficulties in obtaining

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drivers and peripherals parts. The second solution has been to create a dual-boot login to the operating system. This sometimes causes problems on central operating systems that run important data for school or laboratory operations. Another solution that has been implemented is the use of software to simulate the operating system through virtualization. With such simulation, students can run virtual operating systems on the host operating system. In this process, if there is a configuration error or problem with the open-source virtual operating system, it will not have an effect on the host operating system. Over time, practicing through simulations in this virtual environment provides a less real-world experience of how to work and of hardware – driver – OS interaction and leads to a lack of readiness for troubleshooting.

Moreover, based on the observations, it was found that students were less enthusiastic about facing troubleshooting issues when configuring a network operating system in a virtual environment. This is because they were not using real hardware, and the solutions offered by various sources or teaching materials were often irrelevant to the virtual simulation environment. These factors meant the learning process was hindered, resulting in lower learning achievement. This study describes a method to solve problems in learning network operating systems through the application of a single-board microcomputer called the Raspberry Pi.

Previous research has explained the application of the Raspberry pi microcomputer in many fields of IT studies. Its use in computer network research includes its application as a low-cost learning medium [3–6]; as alternative infrastructure to support computer network systems [7–11]; as supporting equipment in computer and robotics laboratories; and even as the main device in IoT and control systems [12–15]. One example of the use of the Raspberry Pi in learning activities is in the teaching of computer networks in distributed system [4]. In this study, it was found that using the Raspberry Pi as a practical tool could improve students' experience in configuring distributed computing. It was also explained that through the use of microcomputers, the campus could provide a number of low-cost practical media so that students could experiment with the concept of a distributed system, which always requires a considerable number of real computers in its application.

In other teaching and learning topics, the Raspberry Pi can be used to teach computer architecture and memory management concepts on the ARM processor [16]. Teachers can also use it to explain the complexity architecture of memory in modern processors. The Raspberry Pi was chosen in this case because this small device

supports modern memory systems, 64-bit architecture, and multilevel caches. Not only used in computer network, the device is also used in the teaching of electrical instrumentation and electronic sensor circuits, which require reliable but straightforward programmable devices [17,18]. Besides being used to support learning, the Raspberry Pi has also been used for low-cost infrastructure, such a media center [7]; cluster computers for complex numerical computing; other general high-performance computing purposes [19]; and as infrastructure for supporting learning facilities with low-cost green technology in a rural area [20].

With reference to previous research, the Raspberry Pi was chosen in this study as an alternative learning medium for teaching computer networks administration. The novelty of the research lies in the implementation of the device as a learning medium in network operating systems and laboratory work in a vocational high school. The application of Raspberry Pi as a learning media for network operating system in vocational high school within the Indonesian context is rarely found in the literature. The vocational high school in Indonesia adopts scientific learning approaches [21]. Students are encouraged to think critically to be able to solve problems they encounter both in daily life or their professional career. Pertinent to network operating systems course, critical thinking and problem-solving skills are prerequisites for students to learn server installation and deployment. Since the designated cases are in resemblance with those in real life, student's familiarity with problems encountered during the course is expected to drive their problem-solving skills as well as psychomotor skills in network operating systems [22].

Regarding network operating systems course, complex network configuration setting potentially causes server misconfiguration that leads to the server running improperly. The complexity of the case given in the course is the challenge for students to involve their troubleshooting ability. Current practices in Indonesia indicate that practicum (also known as a work placement in the UK) in IT vocational high schools relies on simulation-based learning media which inhibits students' psychomotor and troubleshooting skills. Therefore, an affordable, reliable, and outfitted with entry-level computer specifications non-simulation learning media is needed for network operating systems courses.

To measure the impact of the implementation of the Raspberry Pi, several explorations were conducted, including measurement of whether there were differences in the evaluation results between students using virtualized simulation media and ones using the Raspberry Pi.

It was also measured whether there were differences in the evaluation results of the learning network operating systems between students who were interested in the process and those who showed less interest. It was presumed that hands-on learning media such as Raspberry Pi facilitates students' psychomotor development during interaction with the microcomputer devices. In addition, the activities shape students' troubleshooting skills in the taught subject accordingly.

2 Theoretical foundation

2.1 Raspberry Pi

The Raspberry Pi is a low-cost, small-sized, single-board microcomputer that plugs into a computer monitor and uses general input and output peripherals such as a keyboard and mouse. It is a small, highly capable device that enables people of all ages to explore computing since it can run desktop environment operating systems. Not only its general purpose, but with Raspberry Pi users can also learn how to program in languages such as Scratch and Python. The Raspberry Pi substitutes for desktop computers as it has similar components, such as memory, storage, GPU, bus systems, and network modules embedded on the board. Users are enabled to use it for a wide range of activities, such as browsing the internet and playing high-definition video, making spreadsheets, word-processing, and certain entertainment features [7]. Figure 1 below shows the use of Raspberry Pi to operate Ubuntu Linux operating system. The image shown in Figure 1 shows that Ubuntu is installed on a Raspberry Pi device, then displayed using a monitor like an ordinary personal computer but with a much smaller size.

Figure 1: Use of the Raspberry Pi.

The device can be connected to several I/O devices such as a keyboard, mouse, or monitor, meaning it can operate in similar fashion to a desktop computer [17]. It can run several operating systems, such as Raspbian, Ubuntu MATE, Ubuntu Core, and RISC OS [23]. Raspbian and Ubuntu MATE have similarities with Debian OS and Ubuntu OS, starting from the kernel, memory management, file system management, and user-level operations [24]. Therefore, the hands-on laboratory activities of network operating system courses in vocational high schools that usually use Debian OS or Ubuntu OS installed in a virtualization environment can be replaced by Raspbian or Ubuntu MATE. In this study, practice activities were performed using the Raspbian OS installed on the Raspberry Pi.

From previous theoretical studies on several research that have been referred to, the Raspberry Pi has been proven to be applicable in various fields such as supporting devices in Internet of Things (IoT) infrastructure, computer clusters, supporting devices in green computing, computer network infrastructure, complex numerical computing infrastructure, building automation devices, electronic instrumentation, and robotics learning media. In this study, the Raspberry Pi was applied to computer networks learning media, especially for supporting the practical skills of vocational high school students in operating the network operating system. From the explanation that has been stated, it can be assumed that the Raspberry Pi can be used to improve the psychomotor skills and troubleshooting in network operating system course for vocational high school students.

2.2 Network operating system learning

Network Operating Systems is one of the compulsory subjects at information technology vocational high schools. Based on the Indonesian educational curriculum 2013, this course is followed by first-grade and sophomore students. In this research, the data were collected from second-grade vocational students who learn about network operating system course under the guidance of Indonesian national education curriculum standards for information technology vocational high school [25]. Network operating system teaching is conducted using a scientific approach [26], which consists of observing, questioning, associating, experimenting, and networking. Figure 2 below shows the stages of scientific learning which consists of five steps.

The scientific learning method generally consists of five steps, starting with observing, followed by asking questions.

Figure 2: Scientific learning process.

At the observation stage, students can demonstrate their accuracy in retrieving information about installation preparation and the initial configuration of the operating system. At the questioning stage, students develop creativity, curiosity, and critical thinking in order to formulate questions about the operating system that will be or has been installed. This activity may include questions about practical steps, as well as troubleshooting during the practice stage. Furthermore, at the reasoning stage, students can show they can be thorough, honest, disciplined, obey the rules, work hard and able to work according to procedures, and thinking inductively and deductively in completing the operating system material being studied. The networking stage takes place through communication, which is conducted by conveying observations on the conclusions obtained from the learning to other students orally and in writing. The attitudes developed in students related to this networking phase are honesty to get results as they are, thoroughness, tolerance for differences of opinion, the ability to think systematically and to express statements briefly and clearly, and development of correct language skills.

2.3 Network operating system learning materials

The topics studied on the network operating systems course are described in the course syllabus [25]. Most of the syllabus content explains that psychomotor skills dominate the abilities to be achieved by students. These competencies that the students must master include identifying the needs of the server software and hardware; demonstrating how to install network operating systems; demonstrating user management, file systems, and applications;

demonstrating the backup-restore process on storage in a network operating system; demonstrating the installation of network services; and solving misconfiguration and error connections on network operating systems. The learning process to master these competencies usually takes place on the open-source operating system Linux (Ubuntu or Debian), which is installed on computers with a minimum specification (dual-core processor) and a minimum of two gigabytes of RAM. The PC must have a network interface card to connect to the network [2].

These basic competencies can also be practiced with alternative media by using the Raspbian or Ubuntu MATE operating system installed on the Raspberry Pi device. The Raspberry Pi has a multicore processor and RAM specifications like general desktop PCs. There is even an embedded Graphical Processing Unit (GPU) that has processing capabilities like a GPU on a desktop computer. The Raspberry Pi is also equipped with an ethernet or wireless network module, so that it can be connected to a local network, functioning as a host-client or as a router or server [27]. Figure 3 below shows the component parts that support the connectivity of the Raspberry Pi input and output devices. The parts have a function like a personal computer. There is an HDMI port that is connected to the monitor, a Gigabit Ethernet port that is connected to a network cable, a USB port that can be connected to a mouse and keyboard, a microSD storage slot that can be filled with microSD and operating systems, and a Wi-Fi module with a 2.4 GHz frequency, which can be connected to a wireless local area network.

With these specifications, practical activities on the network operating system course start from installation, command-line and GUI-based operations, file system management, user management, backup-restore, and network services. Troubleshooting of the Linux operating system can be carried out on the Raspberry Pi in exactly

Figure 3: Components of the Raspberry Pi similar to a general PC.

the same conditions as in laboratory work using the virtualized operating system installed in VirtualBox.

2.4 Student interest

Student interest is an effective condition and can be shown by anyone. Students at vocational high schools can also be interested or not be interested in a subject. Those who are interested in certain subjects tend to pay more attention [28].

Interest can be defined as an organized disposition through expression. This expression encourages individuals to choose an object, activity, or skill that can increase their proficiency. Interest involves choosing an activity in life, such as following a learning process.

Students' interest in learning network operating systems involves two aspects: whether they are interested in performing teaching activities depending on whether they like or dislike such systems; and whether they are interested in linking practical exercises that are interconnected between these activities [29]. Interest does not happen immediately but is acquired later. Naturally, interest can be shown by anyone and can contribute to learning outcomes. Furthermore, the contribution of interest to learning outcomes will influence the acceptance of new attractions. Therefore, interest in something is the result of learning and supports the success of learning at a later stage.

3 Research method

3.1 Research procedures

In this study, a comparison of the use of two learning media for network operating systems was made; simulation-based using virtualization and in a real environment using the Raspberry Pi. Evaluation between the use of the media was made at state vocational high schools in Central Java, Indonesia.

Most of the network operating system learning activities in vocational high school in Central Java use virtualization-based approaches as simulation media. The introduction of the Raspberry Pi can add to the experience of students of operating network operating systems in real terms and encourage their interest in learning about them, as vocational students have not been introduced to the Raspberry Pi before.

This research is quasi-experimental. According to Cohen et al. [30], this experimental design is the development of a true experimental system that has a control class, but cannot fully function to control external variables that affect the experiment [30]. This study used two groups of students attending network operating system courses in vocational high schools. A nonequivalent control group design was employed, with the total population being 150 second-grade students in six classes spread over vocational schools in Surakarta City, Central Java Province. The sample was determined using the

simple random sampling technique. The model developed and used in the study comprised two classes, namely XA class as the control group and XB as the treatment group. The group which became the sample was taken using the probability random sampling technique. From the results of the sampling, XA class, with a total of 30 students, and XB class, with a total of 30 students, were obtained.

3.2 Data acquisition

The data were obtained using instruments. Those for measuring psychomotor abilities included a job sheet containing a checklist of practical demonstration activities, accompanied by a total of 50 evaluation questions. The indicators of competency achievement are shown in Table 1.

The student interest variables were measured using a questionnaire. This consisted of 25 items containing positive and negative statements about student learning interest in learning network operating systems. The questionnaire indicators of student interest were preparation for practice, interest in attending practice, and the drive to get good results, acts, and happiness. Both of these instruments were valid and reliable.

3.3 Data analysis

The data analysis used in the study was statistical, with selection of the one-sample *t*-test statistic used to determine whether there was a difference in the average between the independent variables and the dependent variable. Before testing the hypothesis with these statistics, a prerequisite test was first conducted, which included a balance test, normality test, and variant homogeneity test [31]. The analysis was performed to prove the hypothesis

concerning the effectiveness of using the Raspberry Pi compared to the virtualization-based approach in network operating system practice. It also included the differences in the efficacy of the Raspberry Pi in the very interested group compared to the less interested one.

The hypotheses of the study are that the Raspberry Pi medium is more effective than the virtualization-based one in learning network operating systems, and that the results of evaluating the practice of groups of students with more interest using the Raspberry Pi medium would be better than those of the group of students with less interest using the virtualization-based approach.

4 Results and discussion

The data in the study can be divided into two phases: pretreatment and posttreatment. Those before treatment contain pretest data from the interest questionnaires and tests of students' initial psychomotor skills in network operating system learning regarding the following competencies: students have several abilities to identify server computer requirements; they demonstrate network operating system installation using CLI and GUIs; they demonstrate user management, file system management, and applications management on network operating systems; they demonstrate knowledge of the backup and restore system file in a network operating system; demonstrate network service configuration ability; and are able to use troubleshooting to repair network operating systems. After treatment, the posttest data are from the interest questionnaires and student skills tests related to activities that must be completed in the network operating system job sheet after treatment is given. The summary scores for the network operating system learning outcomes from the treatment and control groups from the pretest and posttest results can be seen in Table 2.

Table 1: Psychomotor competency achievement indicators

Psychomotor aspect	Learning experiences (Indicators)
Identification (P2)	Students are able to <i>identify</i> server computer requirements.
Demonstrate (P2)	Students are able to <i>demonstrate</i> network operating system installation using CLI and GUIs.
Demonstrate (P2)	Students are able to <i>demonstrate</i> user management, file system management, and application management on network operating systems.
Demonstrate (P2)	Students are able to <i>demonstrate</i> the backup and restore system file in a network operating system.
Demonstrate (P2)	Students are able to <i>demonstrate</i> network services configuration.
Repair (P2)	Students are able to use troubleshooting to <i>repair</i> network operating systems.

Table 2: Comparison of control group and treatment group

Psychomotor skills	Virtualization-based (Control group)		Raspberry Pi (Treatment group)	
	Pretest	Posttest	Pretest	Posttest
Identify server requirements (Skill 1)	72	76	74	76
Demonstrate NOS installation (Skill 2)	71	75	70	74
Demonstrate system management (Skill 3)	68	76	68	72
Demonstrate knowledge of the backup and restore system file (Skill 4)	55	56	56	68
Demonstrate network services configuration ability (Skill 5)	57	58	58	67
Repair using troubleshooting (Skill 6)	42	55	43	66

Table 2 above shows that at the time of pretest, for skillsets 4, 5, and 6, students earn an average grade below threshold of 60. The capabilities achieved in skillsets 4, 5, and 6 require interaction with real hardware directly. Students do not reach the graduation limit, because at the time of the pretest two classes still use simulation-based media. While in the posttest phase, students who learn network operating system using Raspberry Pi are able to achieve above the completeness grade threshold.

In Table 3, it can be seen that the results of the job sheet evaluation, which were analyzed descriptively, show mean pretest scores in the treatment and control group of 61.5 and 60.9, respectively. The average posttest scores are 65.97 for the control group and 70.57 for the treatment group. It can also be seen that the percentage of students completing in the treatment class was 36.7%, increasing to 86.6% posttest. The corresponding figures for the control group show an increase from 40.3 to 56.7%. The data descriptions of the student interest in network operating system practices were obtained using a questionnaire, which was declared to be valid and reliable. The data were obtained from the treatment group class using the Raspberry Pi, and the control group class using the virtualization-based learning medium. The two groups of data were obtained pretest and posttest. A summary of the data on student interest is shown in Table 4.

Measuring interest in the treatment class (Raspberry Pi) and the control class (Virtualization-based) aimed to

obtain data about interest in the lab work activities of network operating system learning. The mean pretest and posttest scores for the treatment group were 81.7 and 85.9, while the mean pretest and posttest scores for the control group were 79.6 and 82.4, respectively.

The data obtained before treatment include data from the job sheet evaluation results and the interest questionnaires on network operating system practical activities for both the treatment and the control class. The assumptions that must be met for the mean similarity test for the treatment and control group are that they meet the requirements for normality and homogeneity. This is intended to show that the data come from a population that is normally distributed and is from a homogeneous population. The decision to make assumptions to meet the requirements of the analysis is made by SPSS. The summary of the normality test results for job sheet evaluation in the experimental class shows a degree of significance of Sig. 0.725, and for the control class it is Sig. 0.903. The figures for the normality test of interest in learning were Sig. 0.651 for the experimental class and Sig. 0.643 for the control class. Because all the dependent variables in the treatment and control groups are higher than 0.05, the data therefore come from populations that are typically distributed.

The results of the multivariate homogeneity test were obtained with SPSS; prior to treatment, it was Sig. 0.211 for the treatment class and Sig. 0.302 for the control class, both of which are higher than 0.05. This shows that the

Table 3: Summary of job sheet evaluation for the pretest and posttest scores in the treatment and control groups

Treatment (Raspberry Pi)		Control (Virtualization-based)	
Pretest	Posttest	Pretest	Posttest
61.5	70.57	60.9	65.97
36.7%	86.6%	40.3%	56.7%

Table 4: Summary of student interest in network operating system practice based on the pretest and posttest Scores in the treatment and control groups

Treatment (Raspberry Pi)		Control (Virtualization-based)	
Pretest	Posttest	Pretest	Posttest
81.7	85.9	79.6	82.4

variance-covariance matrix of the treatment class (Raspberry Pi) and the control class (virtualization-based) is derived from a homogeneous population.

The pretest results from the interest questionnaire were processed using SPSS before treatment, with Sig. 0.511 for the treatment class and 0.502 for the control class, both of which are higher than 0.05. Therefore, there is no average difference between the class that used the Raspberry Pi as a practice medium and the one that used virtualization-based simulations, when examined from the results of the job sheet evaluations and student interest in practical learning of network operating systems. This shows that the data come from a population with normal distribution.

Before the analysis to measure the effectiveness of the Raspberry Pi compared to the virtualization-based approach, an effectiveness test was conducted with a one-sample *t*-test. The results of the job sheet evaluation and interest in learning network operating systems in the treatment class and control class obtained *t*-count values of 2.353 and 6.768. These values are more significant than *t*-table = 1.699. Therefore, the evaluation results of the treatment class job sheet are more effective than those of the control class.

For the group of students who had high interest and learnt to use the Raspberry Pi, the results of the student evaluation of the *t*-count = 0.605, which is lower than the *t*-table 1.699. Students who studied with the Raspberry Pi and had less interest obtained a *t*-count value of 4.839, greater than *t*-table = 1.699. Therefore, the Raspberry medium is more effective for students with high stakes.

Based on the decision criteria in the one-sample *t*-test, the Raspberry Pi is useful in increasing interest and improving the results of the job sheet evaluation of network operating system learning practice activities. This is because students were using the device for the first time. This early experience led to active participation in the practice of network operating systems, thus making the use of the Raspberry Pi effective in improving the job sheet evaluation results on the network operating system course.

In the control class that used virtualization-based simulations, based on the one-sample *t*-test decision criteria, such simulations effectively increased interest in network operating system practices, but were less effective in improving the student job sheet evaluation results for learning network operating systems. This is because students do not participate actively in practical activities. Because the medium is used frequently, students rarely do independent exercises; troubleshooting is also simulated, and students do not use real hardware, so they do

not reflect on what they have done for the next meeting. This is what made the control class learning using virtualization-based simulations less effective in improving the results of the practical job sheet evaluations on the network operating system course.

In Table 2, the six psychomotor abilities measured for the control group and treatment group are shown. If these data are examined carefully, in the three initial psychomotor abilities, namely skill 1, skill 2, and skill 3, there are no significant differences between the groups of students who used the virtualization-based approach and the Raspberry Pi. This is because these skills learned by students do not require direct interaction with hardware. In skills 1, 2, and 3, only the skills to identify and operate the interface, along with menus or features in a network operating system, can be done both in a simulated learning environment using virtualization or a real learning atmosphere.

As for psychomotor skills 4, 5, and 6, there is a significant difference, with the average score of the students in the class using the Raspberry Pi higher than that of the average student in the class using virtualization. This is because the group of students using the Raspberry Pi were dealing with real hardware to complete their work related to the three skills. In these skills, students are required to interact directly with hardware in order to backup and restore system files, configure network services, and perform troubleshooting, activities which cannot be performed in a simulated environment. So, when the group of students using the virtualization-based medium were faced with problems that required interaction with real hardware, they experienced difficulties because they lacked experience in interacting with real hardware.

The abovementioned discussion underlines that Raspberry Pi as an alternative learning media serves for psychomotor improvement pertinent to skill criteria number 4, 5, and 6. Those skillset criteria demonstrate the ability relevant to a file system backup and restore that requires direct interaction with the storage partition, which is hardly found in virtualization-based simulation environments. It is evident that to demonstrate the ability to configure network service configuration requires direct interaction with the physical layer of the computer network which is the Raspberry Pi. Moreover, in order to identify and perform troubleshooting at the hardware level, a direct interaction with the devices is mandatory.

On the other hand, the skillsets number 1, 2, and 3 can be facilitated both using simulation-based model and Raspberry Pi-aided learning media. Identifying server specifications, installing network operating systems, and demonstrating management OS require less contact with the hardware devices. Therefore, it is concluded that

skills related to direct contact with hardware are more optimal if trained with real equipment instead of simulations. Raspberry Pi can be used as an alternative media choice for schools and colleges that have information technology disciplines pertinent to network operating system administration course.

5 Conclusion

Based on the results of the data analysis and discussion, it can be concluded that the use of the Raspberry Pi is more effective in improving practical skills that require interaction with real hardware than the use of the virtualization-based simulation medium. Use of the Raspberry Pi is more effective for students who have high initial interest compared to less interested students. This is indicated by the increase in the level of completeness in the evaluation of the job sheets from students in the treatment class compared to the control class.

The research was limited to exploring the application of the Raspberry Pi to improve students' psychomotor abilities in completing job sheets for practical activities. Further application of the Raspberry Pi in teaching computer networks needs to be explored. Because the Raspberry Pi has the characteristics of a PC workstation, and a scalable operating system, it can be developed into a mini server. In further research, an experiment could be conducted on the implementation of the device as a learning medium for network design on the LAN scale, so students can gain more learning experience by implementing miniature complex computer network topology using TCP/IP technology with real hardware.

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