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Improving Competence Through Virtual Digital Engineering Laboratories with Mobile Virtual Reality

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ABSTRACT

This study aims to describe the use of virtual digital engineering laboratories to raise student proficiency in vocational high schools (VHS). Virtual reality technology was used in virtual laboratories to improve students' learning experiences. This study's methodology was quantitative. Using virtual digital engineering laboratories, student work was compared before and after to evaluate whether there had been an improvement in their level of competency. Each school's average student grade improved when compared to before adopting a virtual digital engineering laboratory. The findings of this study showed an improvement in the scores at each of the three schools where data was gathered. With a total of 15 students, State VHS 2 Yogyakarta saw a rise in scores from 2.56 to 6.37, and the number of students with scores above 70 increased from 0 to 11 at first. In contrast, State VHS 2 Depok, which had 32 students, had an increase in scores from 5.26 to 8.01 and a jump from 7 to 28 in the proportion of students who received a score of at least 70. In contrast, the number of students with scores above 70 increased from 10 to 23, and the scores in State VHS 2 Wonogiri increased from 6.34 to 8.26 out of a total of 31 students.

1. Introduction

Virtual laboratories have the advantages of being simple to use, simple to understand the theory, offering enough time, fulfilling the theories of knowledge, having a safe environment, and advancing new skills. These advantages are supported by teamwork, comfortable settings, and more practice time [1]. The following criteria must guide how virtual laboratories are set up

i. Virtual laboratories must have physical characteristics that work with actual laboratory equipment;
ii. more interactive learning opportunities;
iii. the capacity to provide real-time feedback;

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iv. functionality in tool usage;
v. a virtual display that closely resembles the real world; and
vi. a virtual display is a scene that can be altered to suit specific requirements, such as shrinking, enlarging, or exploring [2,3].

Another advantage of virtual laboratories using VR is that they can cut costs instead of using actual surroundings [2]. Interaction delivers experiences that are not possible in the physical context and is safer than the physical environment [4]. Practice in a virtual setting can be more sophisticated than in a real setting, which enables users to experience learning immediately. Virtual reality produces a lifelike sensation akin to the actual world [5]. Virtual labs will improve student motivation by raising self-efficacy and assignment scores [6].

Emulators in digital techniques have several advantages, including maintaining the original appearance, feel, and behavior of digital things [7,8]. The initial investment in the production emulators is greater, but other costs will be less costly and need less laboratory time. Many authorized and well-developed emulators are available. Applications for emulators can be found in many different fields. The emulator's physical requirements can be reduced back to reduce expenses and practice time. Most emulators can simulate a wide range of electronic components and have a lot of data storage. This work built a virtual lab for digital engineering labs, which were also conducted in three vocational schools. The following research questions can be created based on the context of the problems that are raised

i. How well is the virtual digital engineering lab for high schools with a vocational focus performing?
ii. To what extent are virtual digital engineering laboratories feasible for technical high schools?
iii. What effects do students experience when studying digital methods in virtual labs?

2. Literature Review

Virtual laboratory is one type of technology utilizing existing technological advancements. The implementation of virtual digital engineering laboratories can help increase students' interest in participating in practicum classes in laboratories. Virtual digital engineering laboratory is interactive learning media that aim to improve students' competencies, especially in the field of digital engineering.

Interactive learning in laboratories using smartphones may serve as an alternative learning medium. Smartphones can be put to good use by students in the learning process. One of the most recent smartphone technologies found on Android is virtual reality. Virtual reality technology can change the vision of the real world into a virtual world. The virtual world can be engineered as needed so that it resembles the actual real world according to the programming. Most of the use of virtual reality is currently related to games.

However, the use of virtual reality is not limited to games. One of the uses of virtual reality technology is the simulation of car lifting equipment to see the performance of the car lifting machine by saving manufacturing materials. This makes the use of instructional media by virtual reality more desirable for students because they will practice learning by playing games using an Android device.

One way to utilize technological advancements to meet the needs for laboratories is to create a virtual laboratory [1]. Virtual laboratories can eliminate the possibility of work accidents during practicums. The cost for equipment in the laboratory will also be more efficiently used because the tools and laboratories will be replaced by virtual models with the same functions as the actual tools and laboratories. Users will also know the use of these tools from the procedure provided by the virtual technology. Virtual laboratories have been used in Digital Engineering subject by utilizing computer devices.

Learning conducted in the laboratory focuses on improving the skills of vocational students [2,5,6]. One of the laboratories that must be owned by vocational high schools for practicum processes in the field of electrical engineering is a digital engineering laboratory. However, the majority of vocational high schools do not have a specialized digital engineering laboratory.

These schools have insufficient learning media for conducting digital engineering practices. Digital engineering practicums utilizing learning media are carried out in other laboratories that are not suitable for use. The limited number of learning media also result in inefficient learning because practical learning is conducted in groups. Therefore, some students tend to be less active and less enthusiastic in participating in the Digital Engineering subject.

One of the models of the laboratory is Remote Laboratory which is also referred to as online laboratory [7]. An online laboratory in electrical engineering is an electronics laboratory that can provide students with knowledge, concepts, and technical abilities through a long-term practice. These benefits are comparable to the use of virtual laboratories that can be accessed at any time and from any place. However, conventional laboratories offer the opportunity for the students to solve problems and work collaboratively.

The five characteristics of laboratory management include some aspects called SMART which is the abbreviation of Simple, Measurable, Achievable, Relevant, and Time-bound [9,10]. To increase the quality of virtual laboratories, SMART is required to develop and implement virtual laboratories. The laboratory quality is evaluated based on its accuracy, reliability, and continuous test results [11].

There are also twelve quality systems for laboratory management, namely organization, personnel, equipment, purchasing and inventory, process control, information management, documents and records, occurrence management, assessment, process improvement, customer service, facilities, and safety [11]. These quality systems are useful to assess laboratory quality in the development and implementation process of virtual laboratories.

The security procedures and standards should be applied to assure the security of the management system in the laboratory, especially during emergencies [12]. In conventional laboratories, the security is controlled by technicians whose job is constantly monitoring the laboratories [13]. Safety is a crucial factor to make laboratories to function effectively. [14].

The five features of virtual learning that apply virtual reality (VR) are probability, accessibility, personalization, connectivity, and improving learning motivation [15]. Since the use of virtual laboratories is also built with mobile technology, these features are identical to those of virtual laboratories [16]. Meanwhile, virtual reality is a digital simulation of a 3D world in which people interact by viewing actual things like they would see in real life using special devices including helmets with screens and gloves with sensors [17]. Virtual reality is classified into four categories, namely, VR desktop, Immersive VR, distributed VR, and augmented VR.

A virtual laboratory is convenient to use. This type of laboratory can help teachers/lecturers deliver learning materials more efficiently, so students can better understand the materials. It also provides sufficient time for students to learn mastering certain knowledge. Using a virtual laboratory, practicums are conducted in a safe situation, so it helps students acquire new skills that support the concept of collaborative work. Moreover, this laboratory provides a comfortable environment that allows students to practice longer [18].

Virtual laboratories should be organized based on the following characteristics. First, it must have physical features that are compatible with real-world laboratory equipment. Second more opportunities for interactive learning should be provided. Third, there should be opportunities to give real-time feedback. Fourth, information related to the functions of each laboratory tool should be provided. Fifth, the virtual display should represent the real world. At last, the virtual display is a scene that can be modified to suit requirements, such as reducing, enlarging, or exploring [19].

Another benefit of virtual laboratories with virtual reality is they can increase student motivation [20]. A virtual environment is safer than the physical environment, and it offers experiences that are not available in the physical environment. Conducting practicums in a virtual environment can be more advanced in a way it facilitates the users to directly experience the concept of learning. The virtual reality induces a realistic feeling that is similar to the real environment [21]. Besides, virtual laboratories are able to enhance learning motivation [22].

Several application software will increase students' positive experiences and learning interest [23]. Using ICT through virtual reality laboratories will also improve teachers' skills, experiences, and competences [24]. Sustainable teaching learning processes in virtual environments are established with interactive learning media such as virtual reality laboratory. This phenomenon has replaced the traditional learning media in several schools [25,26].

Students can learn with limited infrastructure and facilities through virtual laboratory, this is on the challenges of virtual laboratory. Thought simulations to display the experimental process, it is a characteristic of virtual laboratory. Before students carry out the real practicum in a conventional laboratory, a virtual laboratory can be a pre-practicum tool. Virtual laboratories have a good impact on student development. Virtual laboratory makes it easier for students to connect to the real world between practical and theoretical aspects [20].

In this study, a virtual laboratory for digital engineering laboratories has been developed using virtual reality [16]. The purpose of this study is to implement the virtual laboratory of digital engineering that has been developed [16] for Digital Engineering subject. This study assessed the feasibilities of the virtual laboratory to apply in learning and teaching process. A laboratory feasibility evaluation was also performed in three vocational schools.

A virtual laboratory was created using Virtual Reality mobile technology. It was built to look like the real-world laboratory. Virtual laboratory movements can be controlled using a Bluetooth remote control which is programmed to perform commands in a virtual laboratory. The users have many options in the virtual laboratory, including learning the theoretical basics of logic gates. There are also logic gate simulations and logic gate circuit simulations.

Figure 1 illustrates the display of the virtual digital engineering laboratory. It provides several objects to be used, and it shows other displays such as simulations of logic gates in digital techniques. In this present study, the virtual laboratory was created to resemble real objects. There are several components of objects, for example computers, whiteboards, tiles, chairs, desks, laptops, ICs, and lamps. When a user uses a virtual digital engineering laboratory, they have the same experience as if they are in the real situation. Objects in virtual laboratories have the same features and properties as real-world objects thus making them impassable and impermeable when the user move toward certain passing objects.

Fig. 1. The display of virtual laboratory room [13,16]

The display of the virtual laboratory has an identical look to real-world objects although it still looks like a visual object. The use of virtual digital engineering laboratories is tailored to real-world laboratory standards. Virtual digital engineering laboratories can save costs on the building of a real laboratory since the components or equipment in virtual laboratories can be obtained easily and without incurring additional costs. Equipment was added to virtual digital engineering laboratories by creating the virtual shapes of real-world objects that are then converted into virtual shapes and 3D shapes. After the shape of the original object was transformed to the 3D ones, the color was changed to match real object color in order to produce a virtual form that resembles real-world objects [27,28].

When the designing process of turning physical objects into virtual objects was accomplished, the objects were put in a virtual digital engineering laboratory as equipment to be used. Objects inserted into virtual laboratories share similar functions that can imitate the appearance and function of real-world objects. The lighting in the virtual laboratory installed above is equivalent to a lamp that illuminates a real-world laboratory. The lights in this virtual digital engineering laboratory generate images of solid objects around them depending on the lamp's location. The cabinets and shelves can be replaced by different equipment to aid the teaching learning processes.

This study aimed to assess the feasibility of a virtual reality-based virtual laboratory developed in Digital Engineering subject. The feasibility of virtual reality learning media was assessed by lecturers, vocational high school teachers, and students as the end users on the learning and teaching process of Digital Engineering subject. This study measures the effectiveness of a virtual reality-based virtual laboratory based on its impacts on students' competences. This study tried to measure the feasibility of the virtual digital engineering laboratory developed for vocational high schools [16]. The impacts of this learning media on students' competences were also measured.

2. Methodology

This study used the method of research and development. On the implementation stage, the virtual laboratory based virtual reality was assessed on the three samples of public vocational high school (Sekolah Menengah Kejuruan Negeri). The considerations of this study using the three samples of public vocational high school are a) the learning achievements of the students at the three public vocational high school are the best performances of SMKN at the district level, and b) the subject of digital engineering was offered at the expertise competency of industrial automation.

This study employed the quantitative method based on the scores on the Likert scale of the questionnaires. This quantitative study involved teachers and students as the respondents who used virtual laboratory products. The questionnaires were distributed to the respondents to assess the feasibility and functionality of the virtual laboratory. The black box questionnaires were used in this study. This type of questionnaire is useful for assessing the functionality of a tool and identifying whether a tool can function properly or if an error occurs. The black box questionnaires were distributed to respondents prior to this study being conducted, so this virtual laboratory could be accepted by end-users in a good condition. To determine the feasibility, the questionnaires distributed to teachers and lecturers were also analyzed prior to being distributed to end-users or students. At the end of this study, end-user questionnaires were distributed to students. This technique was to compare students' learning achievements before and after using a virtual laboratory based on test scores.

The virtual laboratory product quality questionnaire covers four aspects, namely: (1) consistent, (2) interactivity, (3) real-time, and (4) visual. The four aspects were developed into 30 statements. The questionnaire was validated by three lecturers and six teachers of Industrial Automation Engineering subjects from three vocational high schools in Yogyakarta and Central Java. The three lecturers were experts in multimedia, computer, and vocational education. The content validity of the instrument was analyzed by calculating the Aiken V coefficient index with the following formula [24].

$$V = \sum s \; n(c-1) \tag{1}$$

V and s are indexes of respondents' agreement regarding the validity of items, and the score determined by the respondent subtracted by the lowest score (which s = r-1). While r, n, and c are scores of choice category on respondent, number of respondents, and number of choice categories filled in by the respondent.

Regarding to the results, the Aiken validity coefficient index for product quality instruments ranges from 0.704 to 0.926, with an average value of 0.840. The value of instrument reliability which is obtained using the Cronbach's alpha formula is 0.952. The indexes are presented in Table 1 below.

Table 1
Coefficient indexes of virtual laboratory feasibility instruments

No	Aspects	Number of items	Average of V Aiken coefficient index
1	Consistent	12	0.824
2	Interactive	9	0.819
3	Realtime	4	0.88
4	Visual	5	0.837
	Averall		0.840

The testing phase was conducted by giving students knowledge about digital engineering materials using the lecture method. Using this method, students recalled the materials learned in the previous meetings. Then, students were asked to work on pre-test questions that were intended to measure students' learning achievements. The data were collected from SMK N 2 Yogyakarta, SMK N 2 Depok Sleman, and SMK N 2 Wonogiri from 15, 32, and 31 students respectively.

After a week of going through the same learning process, students were asked to use a virtual digital engineering laboratory. Then, they were asked to answer the post-test questions that were based on the same material as the pre-test but the questions were adjusted to the use of the virtual laboratory. Through both tests, the researchers tried to see the differences or increase in students' scores before and after virtual laboratory was used.

After obtaining students' scores, data analysis was performed to determine the increase in scores before and after the virtual digital engineering laboratory was implemented. The data obtained from teachers and lecturers teaching the relevant fields were used to measure the feasibility of the virtual laboratory. Through the black box test performed with the teachers and lecturers, information related to the virtual laboratory function was obtained. Figure 2 shows the how the virtual laboratory was used in a classroom.

Fig. 2. Students conduct virtual practice in digital engineering laboratories

Data were first collected to determine the performance of a virtual digital engineering laboratory. The black box questionnaire data were distributed to lecturers, vocational high school teachers, and students of the electrical engineering education. Data were collected before the virtual laboratory was used by students in the VHSs. The questionnaire contains 30 items that includes the aspects of hardware and software.

3. Results

Virtual Reality mobile technology will be used to create virtual laboratories. Virtual laboratories are designed to resemble physical laboratories. A Bluetooth remote control that has been designed to carry out commands in a virtual laboratory can be used to control movements in the lab. The virtual laboratory offers the user a variety of possibilities, including teaching them the fundamentals of logic gates. Additionally, there exist simulations of logic gates and logic gate circuits. It offers a variety of usable objects and presents additional displays, like digital representations of logic gates. Virtual laboratories are designed to look like real-world items. Computers, whiteboards, ceramics, seats, desks, laptops, ICs, and lights are just a few examples of the various elements found in a virtual laboratory. When a user utilizes a virtual digital engineering laboratory, they have the same experience as if they were in the actual world. The qualities and characteristics of items in virtual laboratories are identical to those of real-world objects, such as desk chairs, which contain complicated characteristics that make them impassable and impermeable when the user sprints toward specific passing objects.

Although it has a shape identical to things in the actual world, a virtual laboratory display is still perceived as a visual object. The utilization of digital engineering laboratories is modelled after actual lab practices. Since adding components or equipment in virtual laboratories may be done quickly and without incurring additional costs, virtual digital engineering laboratories are frequently utilized to save money on creating a physical laboratory. By developing virtual versions of real-world objects and then converting them into virtual and three-dimensional shapes, equipment is added to digital engineering laboratories that operate virtually. The original object's shape is converted to a 3D visual representation, and then the color is adjusted to reflect the object’s actual color. The goal is to create a virtual shape that looks like object. When designing actual objects into virtual objects is finished, the created products can be utilized as tools in a virtual digital engineering lab. The appearance and functionality of real-world things can be mimicked by objects introduced into virtual laboratories. The bulb that illuminates a real-world laboratory is analogous to the lighting in the installed virtual lab above. Depending on where a lamp is placed, the lights in this digital engineering laboratory simulation will produce images of the solid items around. Additionally, some cabinets and shelves that can be transformed into various pieces of equipment are accessible to support practice in a virtual lab for digital engineering.

In this study, questionnaires are intended to provide a score that quantitative methods will process. The use of questionnaires in black box questionnaires, feasibility questionnaires, and the obtained questionnaires was compared to compare users. The maximum score in the black box questionnaires should be 30, indicating that the virtual laboratory was designed flawlessly and functions appropriately. The ratings for the feasibility questionnaires differed since they were evaluated based on the feasibility of lecturers and teachers who teach digital engineering in this virtual laboratory. After using the virtual laboratory, students are subjected to one last test to determine whether their knowledge has increased. After using the virtual laboratory, students are subjected to one last test to determine whether their knowledge has increased. Pre-test and post-test assessments are conducted using identical questions to evaluate the tests and questionnaires. Both the pre-test and the post-test were given at various times. Other factors that distinguish the pre-test and post-test are minimised by the time delay between the two tests' administrations. These three evaluations are meant to help users of this virtual laboratory product and enhance students' comprehension of digital engineering materials. Table 2 displays the data that were obtained.

Table 2
Black box testing results

Name	Aspects		Total
	Hardware	Software	
Lecturer 1	12	18	30
Lecturer 2	12	18	30
Teacher 1	12	18	30
Teacher 2	12	18	30
Teacher 3	12	18	30
Teacher 4	12	18	30
Partner 1	12	18	30
Partner 2	12	18	30

Data retrieval and black box testing were both done to test the viability of a virtual laboratory, along with a feasibility questionnaire that was filled out by lecturers and teachers with expertise in digital engineering education. This stage was preceded by the feasibility assessment before student data collection. Teachers at the vocational school where the data were collected, including VHS 2 Yogyakarta, State VHS 2 Depok Sleman, State VHS 2 Wonogiri, and other teachers who used digital engineering, such State VHS 2 Kendal and Muhammadyah VHS 2 Salam, were the respondents. Along with assessing the virtual digital engineering laboratory, the lecturer also rated the learning media's viability. The outcomes of data retrieval from the feasibility conducted by lecturers with media expertise and teachers in schools are given in Table 3.

Table 3
The feasibility of virtual laboratory

Name	Aspect				
	Consistent	Interactive	Real-time	Visual	Total
Teacher 1	39	28	14	16	97
Teacher 2	33	24	10	14	81
Teacher 3	47	33	16	18	114
Teacher 4	42	30	16	17	105
Teacher 5	48	35	16	20	119
Teacher 6	45	36	16	20	117
Teacher 7	36	27	14	16	93
Lecturer 1	42	33	14	18	107
Lecturer 2	46	34	15	19	114
Total	378	280	131	158	947

To determine if students' test scores improved before and after using virtual digital engineering laboratories, the most recent data collection was done in the form of pre-test and post-test data. Data were gathered from three schools: State VHS 2 Yogyakarta, which has a total of 15 students with expertise in electrical power installation engineering, State VHS 2 Depok, which has a total of 32 students with expertise in industrial automation engineering, and State VHS 2 Wonogiri, which has a total of 31 students with expertise in Mechatronics Engineering. The combined enrollment of the three schools was 78 pupils, and every student got digital engineering instruction from fundamental logic gates and Boolean algebra. The pre-test contained 25 questions tailored to the digital engineering topics covered in the teacher's handbook. The identical questions from the pre-test were utilized in the post-test, which was administered to students about a week after they completed the pre-test, but the phrasing was modified to reflect the use of virtual digital engineering laboratories. Table 4 displays the findings of the data analysis on the scores of 78 students.

Table 4
Competency of the students' improvement

Score Data	Pre-Test	Post-Test
Total	395.2	599.6
Average	5.067	7.687
Number of Students Completed Minimum Criteria Passing of 70	15	62
Number of Students who are not completed	63	14

Data analysis was done to ascertain the degree of eligibility and dependability of the data acquired. A virtual digital engineering laboratory's performance and functionality were to be evaluated via black box data analysis. The data gathered from the black box test indicated that the virtual laboratory capability could be appropriately used without encountering issues. The eight users that used the virtual laboratories demonstrated that the functions aligned with the provided devices. After practicing in the virtual engineering lab for digital engineering, the user performed the black box test, filling it out in accordance with what they had practiced and observed. By offering the lecturer a black box instrument to be evaluated and validated, test data for the black box was verified. The black box instrument also received some alterations so that changes may be made in accordance with the validator lecturer's revisions. The virtual feasibility test for the digital engineering laboratory was validated with the black box test and questions. The validator lecturer commented on the feasibility test instrument and made the indicated adjustments.

The reliability of the virtual laboratory feasibility test was evaluated. Nine users evaluated the viability of a virtual digital engineering laboratory, and their findings were subjected to a reliability test. Nine users participated in reliability testing using the Cronbach's Alpha formula. The feasibility questionnaire's results were accurate, scoring 0.952 out of 30. The results of the reliability test demonstrated the learning medium's dependability for other schools. Based on the user's response to the questionnaire, a feasibility data analysis was performed in addition to the reliability data analysis. Table 5 displays the results of the virtual feasibility test conducted by the digital engineering laboratory's feasibility level.

Table 5
Analysis of data feasibility

Name	Aspect						Category
	Consistent	Interactive	Real-time	Visual	Total	Average	
Teacher 1	39	28	14	16	97	3,23	Worthy
Teacher 2	33	24	10	14	81	2,7	Worthy
Teacher 3	47	33	16	18	114	3,8	Very worthy
Teacher 4	42	30	16	17	105	3,5	Very worthy
Teacher 5	48	35	16	20	119	3,97	Very worthy
Teacher 6	45	36	16	20	117	3,9	Very worthy
Teacher 7	36	27	14	16	93	3,1	Worthy
Lecturer 1	42	33	14	18	107	3,57	Very worthy
Lecturer 2	46	34	15	19	114	3,8	Very worthy
Total	378	280	131	158	947	31,57	Very worthy
Average	42	31,11	14,56	17,56	105,22		
Eligible	Very worthy	Very worthy	Very worthy	Very worthy	Very worthy		

Based on these findings, three instructors and two lecturers provided scores that fell into the practicable group, while five other teachers and two other lecturers provided scores that fell into the highly feasible category. Accordingly, the overall category for the feasibility of the digital laboratory was very practicable based on the number of scores received. Every facet of the feasibility of the virtual digital engineering laboratory was also rated as very viable. The analysis of student test results from the pre-and post-tests, which showed the trend in the students' scores before and after using virtual digital engineering laboratories, was the final step in the construction of virtual laboratories. The first meeting began with the student's receiving instruction in digital engineering, followed by a pre-test to collect data. Students used data analysis to determine the validity of the questions from the pre-test results, and the following findings were made.

The last stage of the development of virtual laboratories was to analyze the data in the form of scores obtained from pre-test and post-test. This analysis is to see the trend of scores obtained by students before and after using virtual digital engineering laboratories. At the first meeting, students were taught about the digital engineering and asked to complete the pre-test. From the results of the pre-test, data analysis was done to check the reliability of the questions.

In the product field trial, the virtual laboratory application was used to teach Digital Engineering subject in three vocational high schools. The students completed the pre-test before the learning process and finished the post-test after the learning process. Students' learning achievement measured from pre-test and posttest were analyzed using the non-parametric test, because one of the requirements of the parametric test, namely the normality test was not met. The results of the

Wilcoxon Signed Ranks test analysis show that the students' scores increased. Table 6 shows the results of analysis on the pre-test and post-test scores.

Table 6
Results of analysis on the pre-test and post-test scores

		N	Mean rank	Sum of ranks
Post-test and pre-test scores from SMKN 2 Depok	Negative ranks	1[a]	2.00	2.00
	Positive ranks	30[b]	16.47	494.00
	Ties	1[c]		
	Total	32		
Post-test and pre-test scores from SMKN 2 Yogyakarta	Negative ranks	2[d]	2.00	6.00
	Positive ranks	13[e]	10.00	130.00
	Ties	0[f]		
	Total	15		
Post-test and pre-test scores from SMKN 2 Wonogiri	Negative ranks	5[g]	4.70	23.50
	Positive ranks	25[h]	17.66	441.50
	Ties	1[i]		
	Total	31		

where *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, and *i* are

a. The post-test average score of SMKN2 Depok is higher than the pre-test average score of SMKN Depok
b. The post-test average score of SMKN2 Depok is higher than the pre-test average score of SMKN Depok
c. The post-test average score of SMKN2 Depok is equal to the pre-test average score of SMKN Depok
d. The post-test average score of SMKN2 Yogyakarta is lower than the pre-test average score of SMKN Yogyakarta
e. The post-test average score of SMKN2 Yogyakarta is higher than the pre-test average score of SMKN Yogyakarta
f. The post-test average score of SMKN2 Yogyakarta is equal to the pre-test average score of SMKN Yogyakarta
g. The post-test average score of SMKN2 Wonogiri is lower than the pre-test average score of SMKN Wonogiri
h. The post-test average score of SMKN2 Wonogiri is higher than the pre-test score of SMKN Wonogiri
i. The post-test average score of SMKN2 Wonogiri is equal to the of pre-test average score SMKN Wonogiri

Table 7 shows the test statistics of the results of pre and post-tests.

Table 7
The test statistics for the results of pre and post tests

	Pretest and Posttest in SMKN 2 Depok	Pretest and Posttest in SMKN 2 Yogyakarta	Pretest and Posttest in SMKN 2 Wonogiri
Z	-4.827[b]	-3.213[b]	-4.306[b]
Asymptotic significance 2-tailed	.000	.001	.000

where a is Wilcoxon Signed Ranks Test, and b is negative rank.

The obtained results indicated that the questions were compiled from 25 reliable items with a score of 0.830, so it could be used in other schools. Post-test data were obtained a week after the pre-test. Based on the students' post-test scores, the average scores obtained by students before and after the virtual digital engineering laboratory was used increased from 5.07 to 7.69 (increasing by 2.62 points). It is shown in the chart that the number of students passing the minimum criteria increased from 15 to 62. Meanwhile, Figure 3 and Figure 4 show the increase in students' mastery of materials after learning using a virtual laboratory.

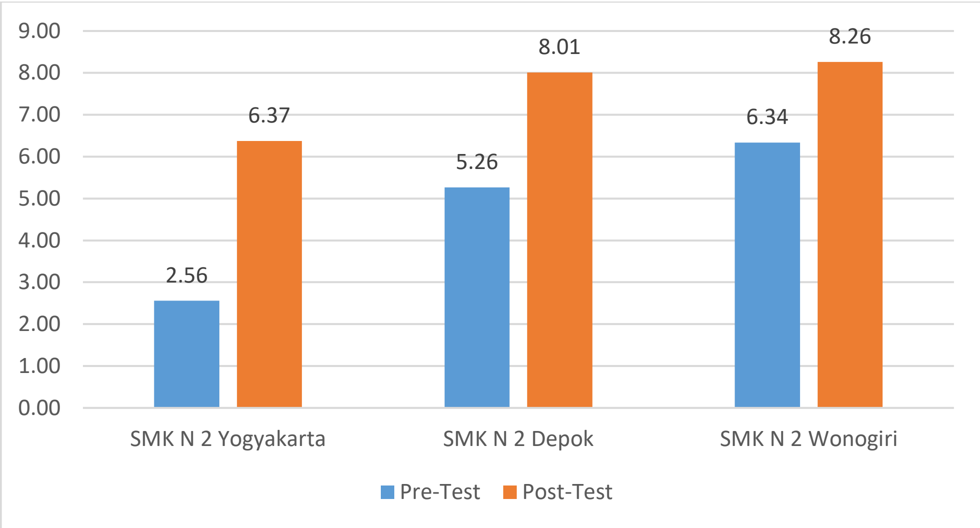

Fig. 3. Average grades for each school

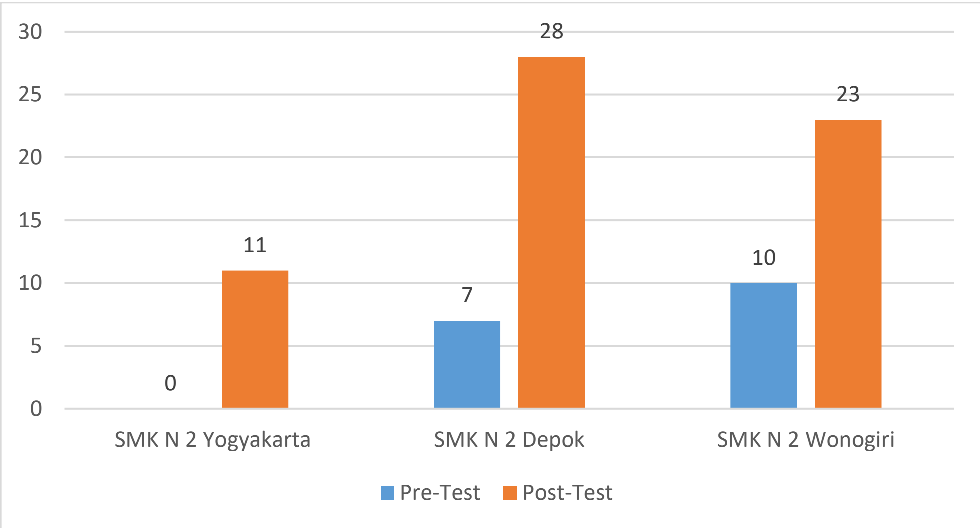

Fig. 4. Completion rate for each school

These findings demonstrated that the 25 reliable questions that were gathered, with a score of 0.830, might be used in other educational settings. The examination of additional data was provided in the form of post-test results around a week after the pre-test. The post-test results revealed that the improvement in scores attained by students before and after using the virtual digital engineering laboratory caused the average score of students who initially scored 5.07 to 7.69 to rise. Using a virtual laboratory raised students' average scores by 2.62 points. On the graph, the number of graduates climbed from 15 to 62, all meeting the required threshold for mastery learning of 70. Figure

3 and Figure 4 depict the improvement in students' competency mastery following use of a virtual laboratory.

Black-box tests are used to determine how well virtual digital engineering laboratories perform. The outcomes of the black box test were used to evaluate virtual digital engineering facilities' hardware and software capabilities [8]. Software must go through system tests, acceptance tests, and usability tests to evaluate the product's functionality forms the basis for the black box test in terms of software. Since virtual laboratories are used in software testing, numerous components, including the device system, display, and algorithm, must be tested. The findings of the data collected from 8 (eight) users received an average score of 18, indicating that the results are consistent with the software element, with 100% of users responding that the usage of the capabilities of the virtual laboratory is based on the software. With regards to functioning and utilization, the virtual digital engineering laboratory provides a number of benefits and drawbacks. Virtual digital engineering laboratories employ virtual reality technology to make digital engineering practical learning more engaging. This is one of its main benefits. b. Smartphones can be used to access virtual engineering labs, making them accessible at all times and locations. c. When studying, some objects are available and can be arranged. d. Lessening the effects of IC equipment damage in the actual lab. According to Persson and Nouri [9] study's findings, real labs (RLs) are also important for in-person instruction, and students generally accept and desire VR-based virtual learning environments (VLs). To expand the experience of utilizing virtual digital engineering laboratories, additional equipment is needed. This is just one of the disadvantages of virtual digital engineering laboratories. b. Because use is still offline, students can only use media on their own and not collaboratively. c. Circulation does not include the act of putting together several digital techniques; it merely modifies the simulation's input. According to Roychoudhury [10], assessment of the viability of a virtual laboratory, there are five requirements that must be met while creating a virtual laboratory. 1) The virtual laboratory equipment's features must be consistent with those of the actual laboratory equipment, and 2) Interactivity increases learning. 3) The capacity to offer real-time commentary. 4) Utilizes tools effectively, 5) The virtual display is a view that can be altered as needed, including lowering, enlarging, and exploring. Virtual appearance is identical to the real environment. In the context of online labs for digital engineering. Several aspects are taken, including Consistent Aspects, Interactive Aspects, Realtime Aspects, and Visual Aspects. Each aspect was assessed based on a questionnaire that was tested on media experts and teachers teaching digital techniques. The consistent aspect is an aspect for assessing the consistency of virtual objects with real objects seen from the component dimensions and characteristics of these objects. In this aspect, there are 12 questionnaire items and an average value of 3.67 is obtained from the results of the due diligence conducted by experts, which means that the digital engineering virtual laboratory is in the very feasible category. The teachers' due diligence yielded a total of 7 (seven) teachers with an average score of 3.45 who fell under the Eligible group. The interactive component helps to gauge how interactively users would participate with virtual digital engineering laboratories. The characteristics of student engagement and comfort in using the virtual laboratory reveal how interactive it is. The interactive component consists of nine questionnaire questions with average scores of 3.72 on expert judgment, which is classified as extremely feasible, and 3.38 on teacher assessment, which is classified as practicable. This demonstrates that the virtual laboratory for digital engineering is interactive in terms of usability and student enthusiasm in engaging in digital engineering learning. It demonstrates that many of the same learning mechanisms are used when using virtual labs for engineering and other scientific disciplines. Introducing more general engineering knowledge and encouraging the introduction of new concepts as part of learning about science and technology are two examples of how this can be done, as well as supporting more constructive (and collaborative) education and training activities in a more complex engineering topic [14].

Real-time analysis is one way to learn how responses and input from virtual digital engineering laboratories were received. Direction responses and command responses from the virtual laboratory are used as a reference in the assessment. The two outcomes of the due diligence are rated as extremely practical because the results acquired based on the expert are worth 3.63 and the results given based on the teacher's judgment are worth 3.64. There are 4 (four) survey questions based on command and direction responses in this real-time element. The visual aspect is used to evaluate how closely visual shapes in virtual laboratory things match those in actual laboratory objects. The visual resemblance of the equipment and the similarity of the work process are the two (two) dimensions from which the similarity assessment is viewed. The test results by the digital engineering teacher received a score of 3.46, which was classified as possible, and the visual aspect assessed on 2 (two) specialists received an average score of 3.7, which was classified as highly practicable. The outcomes of this experiment demonstrate how visually comparable real things are to those used in virtual digital engineering laboratories. Virtual engineering labs are a generally acceptable alternate learning environment that can be used for digital engineering practice in vocational schools. According to the study by Vergara *et al.,* [12] and Ibrahem *et al.,* [15] students of general health colleges majoring in microbiology had improved cognitive loads and laboratory skills when using virtual labs. Viewed from the perspective of the learning outcomes of digital engineering practices is the impact of a virtual digital engineering laboratory. The results revealed a substantial difference between the three schools' pretest and posttest, proving that the virtual impact of digital engineering laboratories can raise scores for competency in the field. The virtual laboratory can help students learn digital engineering methods more effectively because it offers an alternative to using laboratories for practice. The virtual bioprocess engineering laboratory was shown to help students better understand the concepts of fermentation, laboratory safety, experiment design, and data analysis, which is consistent with the findings by Khairudin *et al.,* [16]. The results show that a virtual reality bioprocess engineering lab can provide a quick, secure, and affordable learning environment for gaining the required skills and competencies. More than 90% of students believed that the virtual lab was essential for carrying out successful practical experiments.

Different limitations apply to this study's construction of virtual digital engineering laboratories. There are certain limitations, such as the fact that the virtual laboratory for digital engineering only provides access to two types of content: material for basic logic gates and content for Boolean algebra; The information in the virtual laboratory is similarly limited to a summary of the VHS handbook content used to modify the information there, with only nine practicable circuit simulations and seven logic gate simulations usable; The study only includes three universities, spread across different areas.

4. Conclusions

The black box test tool measures performance in virtual digital engineering labs in line with the functions of the virtual lab. The user reported that the software and hardware aspects were suitable in the black box test, resulting in a satisfactory performance rating for the virtual laboratory. Four criteria were used to assess the viability of a virtual laboratory: consistent, interactive, real-time, and visual. Seven teachers who supported digital engineering instruction and two media specialists deemed the virtual lab feasible and evaluated each component. Interactive, real-time, and visual media can each receive scores that are incredibly deserving in terms of consistency. When students from various schools use a virtual engineering lab, their scores have improved. By improving the effectiveness of the digital engineering virtual laboratory development in vocational high schools, further product development can be carried including features to facilitate the use of virtual labs for digital engineering and improve the performance of virtual laboratory use in line with virtual laboratories for digital engineering; creating virtual laboratories for digital engineering that can be created online and encourage student collaboration to boost the viability of employing virtual laboratories, and increasing the quantity or caliber of the material to affect how valuable and knowledgeable students in other professions are.

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