Effective virtual laboratory to build constructivist thinking in electrical measurement practicum

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ABSTRACT

Constructivism serves as a basic theory in education, and plays an important role, because this perspective views learning as a dynamic process in which students actively participate in constructing their knowledge. So, this research aims to produce a virtual laboratory that is valid and effective in developing constructivist thinking. This research and development use the Ploom approach which consists of initial investigation, design, construction/realization, testing, evaluation, revision, and implementation. Thirty-two electrical engineering students from Padang State University participated in this research. The instruments used are validity instruments and constructivism assessment tools. The research results show that the Proteus-based virtual laboratory developed is valid and effective in fostering constructivist thinking in electrical measurement practice. This study contributes to the advancement of virtual laboratories in educational settings, emphasizing the importance of constructivist pedagogy for meaningful and engaging learning experiences in the field of electrical engineering. The results of this research open opportunities for further research regarding the exploration of artificial intelligence to improve constructivism through virtual laboratories.

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1. INTRODUCTION

Engineering education aims to produce graduates who have high technical skills and competencies. To achieve this goal, learning in engineering education must emphasize practicum. Practicum is a learning activity carried out directly in a laboratory or workshop [1]. Practicum provides students with the opportunity to develop their technical skills and competencies [2]. Likewise, in the field of electrical engineering, one of the courses that plays an important role is the electrical measurement practicum. This course is designed to equip students with the skills and competencies needed to carry out electrical measurements [3]. Likewise, in the field of electrical engineering, one of the courses that plays an important role is the electrical measurement practicum. This course is designed to equip students with the skills and competencies needed to carry out electrical measurements.

Virtual laboratories can be an innovative solution to overcome various limitations that often occur in carrying out conventional practicums in physical laboratories [4]. One of the main advantages is the financial aspect, where virtual laboratories tend to be more economical, reducing the cost burden that is often associated with procuring practical materials and maintaining equipment [5]. Time flexibility is also a major attraction, making it easier for students to access and undergo practicum according to their schedule, which may not always be possible in conventional practicums which have limited time [6]. In addition, virtual laboratories have a positive impact on safety aspects [7]. Safety risks generally associated with conventional practicums can be minimized in a virtual environment, thereby providing a safer and more comfortable learning environment [8]. Students can conduct experiments without worrying about possible accidents or exposure to hazardous materials. This not only creates a safer learning environment but also frees students from concerns regarding safety aspects which often become obstacles in carrying out conventional practicums [9]. With all its advantages, the virtual laboratory has extraordinary potential which can be utilized optimally in the context of practical electrical measurements.

Practical learning is learning that emphasizes technical understanding for students, this is in line with constructivist thinking. Constructivist thinking emphasizes the active role of students in the construction of knowledge through direct experience [10]–[13]. In this paradigm, learning is not just the delivery of information to students, but rather the process of constructing knowledge by students through interaction with learning material and the environment [14]–[17]. In the practical context of electrical measurements, constructivist thinking is applied by providing opportunities for students to not only receive information about electrical measurements, but also be actively involved in the measurement process itself. Through exploration, experimentation, and discussion, students can build their own understanding of electrical measurement concepts [18], [19]. Therefore, virtual laboratories become relevant in the context of constructivist thinking. The virtual laboratory provides a platform that allows students to experience electricity measurement practice interactively and independently. By conducting virtual experiments, students can construct their own knowledge about electrical measurements. This strengthens the connection between constructivist thinking and electrical measurement practice, where students not only receive information, but also build understanding through direct experience.

Various previous studies have detailed the success of virtual laboratories in various aspects, such as research conducted by [20] who developed a virtual laboratory for mechanical engineering learning, especially in the context of fluid mechanics. The research results stated that most lecturers stated that virtual laboratories helped in the teaching process and improved teaching skills, and students stated that virtual laboratories could improve understanding of fluid mechanics concepts. The results of this research show that the virtual laboratory provides an in-depth learning experience and increases students' understanding, thereby improving their academic abilities. Another research conducted by [21] focused on the implementation of Android-based virtual laboratories in vocational schools in the context of civil engineering education. The findings of this research show that students who take part in practicums using virtual laboratories have a better level of understanding of concepts and practical skills compared to students who take part in conventional practicums in physical laboratories. This underlines the potential of virtual laboratories in increasing the effectiveness of learning in vocational schools. Research conducted by [22], where the research involved 72 educational institutions in Nigeria in implementing a constructivist approach. The findings show that there is a significant difference in mean scores between the constructivism group and the non-constructivism group. These findings confirm that learning through the constructivist model paves the way to meaningful, interesting learning and active participation and functions as a motivational factor in learning. Based on previous studies that have investigated the impact of virtual laboratories on learning but have not explicitly explored the impact of virtual laboratories on other learning approaches. Meanwhile, there is a constructivist approach that has been studied separately which can have a positive impact on learning. So, there is a research gap that needs to be explored to investigate the impact of virtual laboratories on constructivism.

Previous research has proven the success of implementing virtual laboratories in various aspects but has not explicitly explored the impact on constructivist thinking in the context of electricity measurement practicum. This gap shows that research is still needed to find out how to apply virtual laboratories to support the principles of constructivist thinking in practical learning of electrical measurements. Based on this, researchers designed an effective virtual laboratory to build constructivist thinking in electrical measurement practicum. An in-depth exploration of the success of virtual laboratories in building constructivist thinking is an important step in advancing the field of electrical engineering education.

2. METHOD

This research is research and development using the development model approach proposed by Ploom. Ploom is an approach that focuses on developing a model or product through a series of structured stages [23]. The stages in this methodology include initial investigation, design, realization/construction, testing, evaluation, revision, and implementation. The first stage, preliminary investigation, involves gathering information to discover the problem, and analyzing the need to design an appropriate solution. Next, the design stage leads to product design based on the results of the investigation. The realization/construction stage includes implementing the design in concrete form to produce a pre-production product. After that, in the testing, evaluation and revision stage, the pre-production product will be thoroughly tested, evaluated, and revised if necessary to ensure suitability for the research objectives. The final step is implementation, where the product being developed will be applied in an appropriate context. By following a series of structured stages, the aim is to develop an effective virtual laboratory for developing students' constructivist thinking in electrical measurement practicum. The research procedures carried out can be seen in Figure 1.

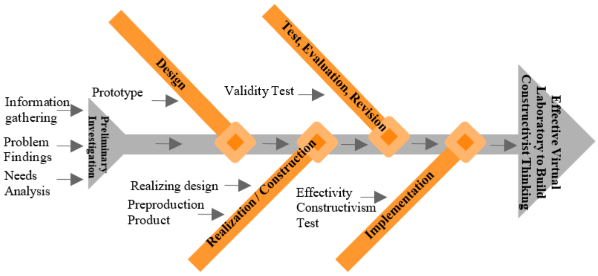

Figure 1. Research procedures

The sampling technique used in this research was total sampling, which means that the entire relevant population was taken as a sample. Therefore, this research was conducted on 32 electrical engineering students at Padang State University who were taking practical electrical measurement courses. The instruments used in this research consisted of validity instruments and constructivism instruments. The validity of the instrument was given to 3 media experts and an electrical measurement expert. The validity indicators assessed by the validator can be seen in Table 1. This validation process aims to ensure that the instruments used have a high level of validity and can be relied upon to measure the variables studied.

Table 1. Validity indicator

Indicator	Description	No. item
Curriculum alignment	The extent to which the products is in accordance with the curriculum	1, 2, 3
Ease of operation	The extent to which the product is easy to operate	4, 5, 6, 7
Instructional clarity	The extent to which the product is instructionally clear	8, 9, 10, 11, 12
Safety	The extent to which it is safe to use the product	13, 14, 15, 16
Design	The extent to which product design can attract students' attention	17, 18, 19, 20

Once the instrument is given to experts, their assessments are collected for analysis to determine its validity. This process considers whether the product is considered valid or not based on the value given by each expert to each indicator item. A product is declared valid if the value given by each expert for each indicator item has a value ≥0.6, while it is considered invalid if the value is <0.6. To analyze the validity of the instrument, the Aiken's V validity coefficient is used, which provides a more detailed picture of the validity and consistency between the assessments of various experts. The Aiken's V validity coefficient formula is as (1):

$$V = \sum S/[n(c-1)] \quad (1)$$

description: V=Aiken validity index, n=number experts, c=number of criteria, S=$\sum$ ni (r-lo), ni=number of experts who chose i criterion, r=i criteria, and lo=lowest rating.

After Padang State University Electrical Engineering students underwent electrical measurement practice using a virtual laboratory, they were given constructivism instruments to fill out. This instrument aims to measure the extent to which students have been involved in a learning process centered on constructivism. The indicators used in this constructivism instrument are based on the constructivist multimedia learning environment survey (CMLES) [24]. CMLES has undergone validity and reliability tests by previous researchers [25], which confirmed that this instrument is accurate and consistent in measuring constructivism. The CMLES indicators used to measure constructivism can be found in Table 2.

Table 2. CMLES constructivism indicator

Indicator	Description	No. item
Student negotiation	Extent to which students have opportunities to discuss their questions and their solutions to questions.	1, 2, 3, 4, 5
Inquiry learning	Extent to which students are encouraged to engage in inquiry learning	6, 7, 8, 9, 10
Reflective thinking	Extent to which students have opportunities to reflect on their own learning and thinking.	11, 12, 13, 14, 15
Authenticity	Extension to which the information in the program is authentic and representative of real-life situations.	16, 17, 18, 19, 20
Complexity	Extent to which the program is complex and represents data in a variety of ways.	21, 22, 23, 24, 25

After the questionnaire data is collected, the next step is to analyze it to find out the average answer score for each indicator. This process aims to understand how well respondents respond to each aspect measured by the indicators in the questionnaire. The formula used to calculate the value of effectiveness can be seen in formula (2). After the average score is obtained, the value of each indicator will be compared with the previously determined effectiveness category which can be seen in Table 3. The table provides guidance on how to interpret the results of the values for each indicator.

$$av = \frac{xi}{\mathrm{n}}\ x\ 100\% \quad (2)$$

Description: av=constructivism score, xi=Average value of the i-th indicator, and n=Number of i-th indicator items.

Table 3. Validity indicator

Score	Category
85-100	Very effective
75-84	Effective
60-74	Moderately effective
55-59	Les effective
0-54	Ineffective

3. RESULTS AND DISCUSSION

3.1. Design result

In the design stage, researchers develop a design framework to create the desired virtual learning environment. At this stage, the conceptual arrangement and basic structure of the virtual laboratory to be built are designed. Once the design framework is established, the next step is to select the most appropriate software to realize the vision. Through analysis of research needs and objectives, researchers examined several factors, including wide component availability, complete measurement facilities, flexibility in printed circuit board (PCB) design, integration of design and simulation functions, and microcontroller support. Based on these considerations, the researchers decided to use proteus as the main software in implementing the virtual laboratory. Proteus is electronic design software that helps designers in the conceptualization and documentation of electronic circuits [26]. It includes dual functions in one package, functioning both as schematic drawing software and as a tool for designing drawings for PCBs [27]. Proteus software offers a variety of libraries containing various components. These components include passive elements, analog components, transistors, silicon-controlled rectifier (SCR), field-effect transistor (FET), various types of buttons and switches, digital integrated circuits (IC), amplifier ICs, programmable ICs (microcontrollers), and memory ICs. In addition to its rich component library, the software is equipped with a variety of measurement instruments [28]. These instruments include voltmeters, ammeters, oscilloscopes, signal analyzers, and frequency generators, providing a comprehensive toolkit for experimental exploration and analysis in a virtual laboratory environment [29]. With the various advantages offered by Proteus, it will be used to build a virtual laboratory to study electrical measurement practices.

3.2. Realizing result

3.2.1. Work page

The work page functions as a special workspace used for designing and simulating electronic circuits based on the worksheets provided. Within this page, users have access to various menus specifically designed to facilitate and improve their tasks. These menus are carefully integrated to provide users with comprehensive tools and functions, simplifying their workflow and optimizing electronic circuit design and simulation processes. The work page display can be seen in Figure 2.

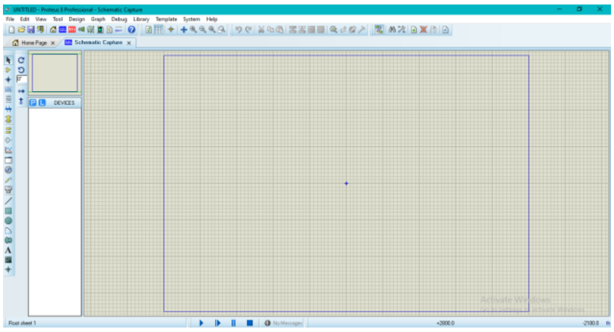

Figure 2. Work page

3.2.2. Component's page

The components page is an important section that provides a variety of electronic components that are important for laboratory experiments. Components such as power supplies, resistors, inductors, capacitors, voltmeters, ammeters, and others are easily accessible for integration into practical circuit simulations. On the left side of the component page there is a complete toolbar, this toolbar includes various modes, including selection mode, component mode, terminal mode, generator mode, and instruments. The component page display can be seen in Figure 3.

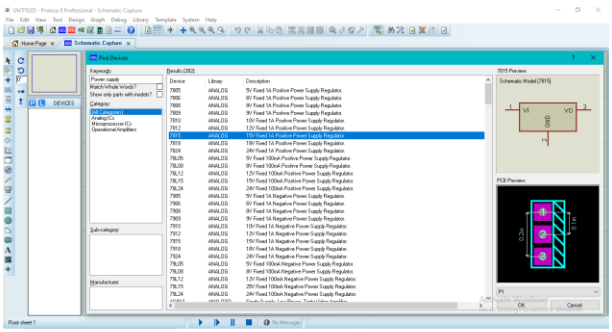

Figure 3. Components page

3.2.3. Project framework

Derived from the worksheets used, designed specifically for the electrical measurement practices course, the subsequent virtual laboratory framework design encapsulates an objective structure that aligns with the course objectives. This framework serves as a blueprint that brings together the essential components and functions required for an effective virtual learning environment in the field of electrical measurements. The design is carefully crafted to adhere to the tasks and experiments outlined in the worksheet. This framework is carefully structured to reflect the hands-on experiences students will encounter in a physical laboratory environment, thereby encouraging a deep and enriching learning journey. Within this framework, students can navigate various sections and modes, accessing electronic components, measurement instruments and simulation tools relevant to the electrical measurement practice course. The project framework page display can be seen in Figure 4.

3.2.4. Simulation process

Simulation in proteus is an important phase that aims to validate and test a series of tasks to be solved. This simulation stage functions as a virtual environment where the functionality of the tools and components can be observed, mirroring the operation of conventional laboratory instruments. During the simulation, intricate details about the function of each tool or component are carefully examined. The importance of simulation lies in its preventive nature-potential errors or inaccuracies can be identified and corrected without risking equipment damage or compromising safety. Through the simulation environment, students gain valuable insights, refine their designs, and ensure that the actual implementation aligns with the expected results. The simulation process page can be seen in Figure 5.

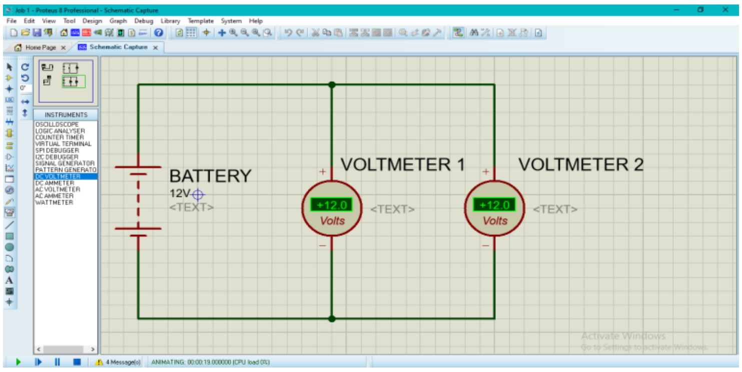

Figure 4. Project framework

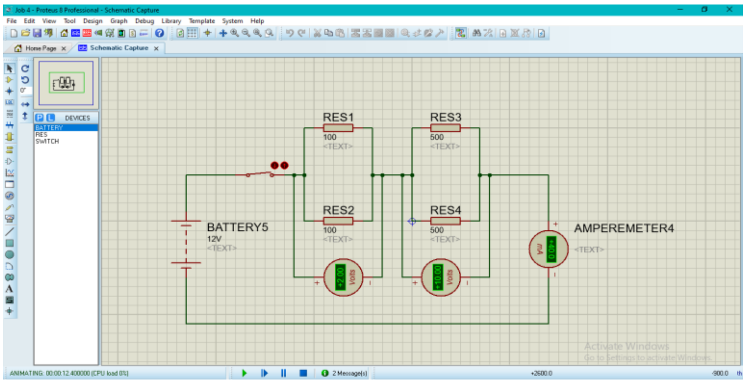

Figure 5. Simulation process

3.2.5. Simulation and discussion report

After completing the electrical measurement practicum in the virtual laboratory, students continue by compiling a video presentation of their simulation project. This video presentation is a forum for sharing the results of his work with fellow students via e-learning at Padang State University. In the video, students explain in detail the purpose of the project, the steps taken, and the electrical measurement results obtained through the simulation. Apart from presenting video presentations, students are also actively involved in group discussions on the e-learning platform. They can exchange opinions, ask questions, and provide responses to the simulation projects that have been presented. The report page can be seen in Figure 6.

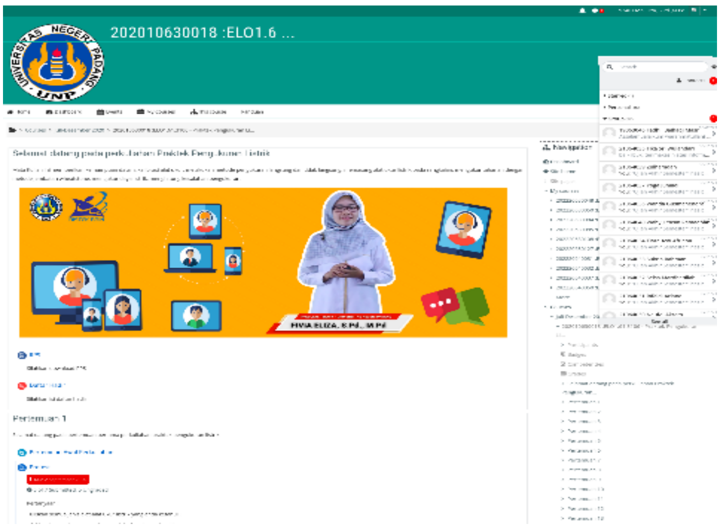

Figure 6. E-learning

3.3. Test and implementation result
3.3.1. Validity test
At this stage, a validity test of the product being developed is carried out. The validity test is carried out with an assessment by 3 media experts and an electrical measurement expert. Based on the results of the validity test on the curriculum alignment indicators, the validation results show consistent values from the three validators, namely 0.8, 0.7, and 0.8. These values show that the virtual laboratory has been successfully integrated according to the applicable curriculum. The easy to operate indicator also received high ratings from the three validators, with scores of 0.7, 0.9, and 0.8. This indicates that the virtual laboratory is designed to be easy for users to operate. The clarity of instructions indicator also received a positive assessment, with a score of 0.8 from validators 1 and 3, and 0.7 from validator 2. This shows that the virtual laboratory provides clarity in the instructions delivered to users. The safety aspect is the focus, and the validation results show a consistently high score from the three validators, namely 0.9. This value reflects that the virtual laboratory is considered safe to use without significant safety risks. On design indicators, the virtual laboratory also received a consistent score of 0.8 from the three validators. This shows that the design of the virtual laboratory is considered adequate and in accordance with the expected standards. Thus, based on the validation results, it can be concluded that the virtual laboratory has met the validity criteria that have been set, with consistent values and reaching or exceeding the specified thresholds. A summary of the validity test results can be seen in Figure 7.

3.3.2. Effectivity constructivism
At this stage, a constructivism test was carried out to determine the extent to which the virtual laboratory can facilitate learning experiences that create sustainable and relevant knowledge construction. Based on the constructivism test, the results obtained on the student negotiation indicator obtained a score of 82, which shows that students have a good opportunity to discuss questions and resolve them effectively. The negotiation process between students in a virtual laboratory environment succeeded in providing a space for productive interaction. Furthermore, on the inquiry learning indicator, a score of 80 reflects that students have been successfully encouraged to carry out inquiry learning. Virtual laboratories provide effective stimulation to encourage students to actively participate in exploring concepts and constructing their own knowledge. On the reflective thinking indicator, a score of 88 indicates that students have a very good opportunity to reflect on their own learning and thinking. Students' ability to organize their understanding through reflection has proven to be very effective in a virtual laboratory environment. Furthermore, on the Authenticity indicator, a score of 85 indicates that the information presented in the program is authentic and represents real life situations well. Virtual laboratories successfully create learning situations that are relevant to everyday life, increasing the authenticity of students' learning experiences. Finally, on the complexity indicator, a score of 78 indicates that the program provides effective complexity in representing data in various ways. This level of complexity provides just the right challenge to enhance student understanding without making it too complicated. With high scores for each indicator, it can be concluded that the virtual laboratory is able to make a positive contribution to the development of students' constructivist thinking. Overall, the results of the constructivism test show that the virtual laboratory is effective in providing learning experiences that support students' constructivist thinking. A summary of the constructivism test results can be seen in Table 4.

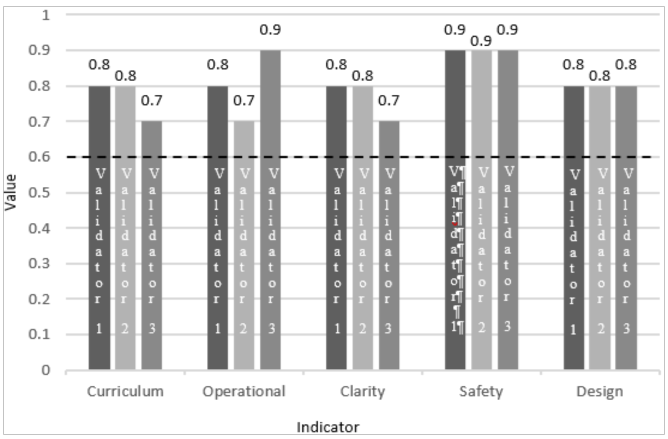

Figure 7. Validity result

Table 4. Effectivity constructivism result

Indicator	Score	Category
Student negotiation	82	Effective
Inquiry learning	80	Effective
Reflective thinking	88	Very effective
Authenticity	85	Very effective
Complexity	78	Effective

3.4. Discussion

Based on the results of the validity test, the virtual laboratory received a positive assessment in terms of component availability, ease of operation, clarity of instructions, safety and overall design. This provides a strong basis for believing that the virtual laboratory used in measuring constructivism has high accuracy and precision. As a result of the constructivism assessment, the virtual laboratory proved to be a powerful and effective tool for enhancing the practical learning experience of electrical measurements. these findings demonstrate that the virtual laboratory is a valuable and reliable tool for electrical measurement practice. It not only aligns with the educational curriculum and operates effectively but also successfully fosters a constructivist learning environment.

These findings clearly refer to the concept of constructivism in the learning context. Constructivism theory emphasizes the importance of student-centered learning, where students are actively involved in building their own understanding through direct experience, reflection, and interaction with subject matter. In other words, constructivist learning considers students as builders of their own knowledge, not as passive recipients of information. In this case, the virtual laboratory has succeeded in creating a learning environment that allows students to participate actively in the learning process. Students' active involvement in learning, as observed in these findings, is also in line with the principles of constructivism. According to this theory, students learn better when they are actively involved in the learning process, rather than simply receiving information from the teacher or other external sources. Virtual laboratories encourage active student involvement by providing a variety of simulations and experiments that allow students to test their theories directly which sparks their interest and motivation to learn. Apart from that, through discussion media students can also discuss with each other and share experiences in working on simulations. The integration of technology with a constructivist approach is in line with contemporary educational paradigms, serving various learning styles and encouraging student-centered learning.

The results of this research are in line with the findings of previous research conducted by [30], where he developed a pedagogical framework for mobile-assisted language teaching and learning. In this research he stated that language teaching that meets the principles of social constructivism can improve authentic language environments and increase contextual awareness. Because the basic concept of mobile pedagogy comes from social constructivism that educational activities occur in a continuous development process within the framework of knowledge through practice in a particular cultural community. Therefore, social constructivism provides a theoretical foundation to support teachers in adopting mobile pedagogy in the digital era. In line with this, research findings conducted by [31], the results of his research explain that constructivism-based learning has a positive influence on students' higher thinking abilities, in the learning process students experience increased activity, increased interaction, and increased student learning motivation. In another study conducted by [32]. The research findings confirm that engineering education modules created based on a constructivist approach can improve student engagement, learning achievement, inclusivity, and better resource utilization at lower costs. The continuity of research results conducted by researchers with previous research provides a strong foundation for further development in designing electrical engineering learning approaches that are innovative and relevant to the development of technology-based learning. However, the limitation of the research carried out lies in that the scope of the research is only limited to electrical engineering students at Padang State University, so it is necessary to generalize the findings carefully to a wider population. And this research focuses on the effectiveness of the Proteus-based virtual laboratory in building constructivist thinking in electrical measurement practicum and does not consider the influence of external variables that might influence the results. So, it is necessary to carry out further studies by expanding the sample scope and considering relevant external variables to gain a more comprehensive understanding of the effectiveness of virtual laboratories in a broader context.

Thus, the findings of this study provide insights for future development and optimization of virtual laboratories to further increase their impact on student learning outcomes. These positive results highlight the potential of virtual laboratories to enhance the overall learning experience in technical education, providing a platform that not only validates but also encourages more robust student constructivist thinking rather than simply improving learning outcomes. Future research could explore virtual laboratories with the integration of artificial intelligence to produce better learning.

4. CONCLUSION

The conclusion of this research shows that the virtual laboratory designed and evaluated for its effectiveness in building constructivist thinking in the context of electrical measurement practicum has been successful. Evaluations conducted by expert validators show consistency and positive acceptance of this virtual laboratory in terms of curriculum alignment, ease of operation, instructional clarity, security, and design. The results of constructivism testing also show that the virtual laboratory is effective in developing constructivist thinking in students. Students engage in the learning process well, demonstrating strong skills in negotiation, effective discussion, as well as proficiency in inquiry learning and reflective thinking. The authenticity of the learning environment is evident, and the complexity of the program provides students with challenges appropriate to their level of understanding. Thus, the virtual laboratory not only meets but also exceeds the established criteria, making a significant contribution to the development of students' constructivist thinking. Recent observations confirm that this virtual laboratory effectively builds constructivist thinking in practical learning of electrical measurements. These findings provide conclusive evidence that the integration of virtual laboratories into the existing curriculum will have a significant positive impact, especially in building students' constructivist thinking. This research opens up opportunities for further exploration in the future by exploring virtual laboratories with the integration of artificial intelligence to improve student learning experiences and further assess their impact on long-term learning outcomes.

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