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Design Digital Twin Technology for Practicum Distance Learning

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Abstract: One effective way to carry out laboratory practicums remotely is by using digital twin technology. This study investigates the feasibility and user response to using digital twin technology for remote Basic Electrical Energy practicums. This study employs a Research and Development (R&D) method involving students from the Department of Electrical Engineering. A validation sheet and a questionnaire were used to assess feasibility and user responses, respectively. The feasibility results of digital twin technology for remote practicums according to media experts obtained. The feasibility test achieved 90.71% from material experts and 91.43% from media experts from media experts, categorizing the system as "highly feasible." User responses were also positive, with scores of 88.25% for material presentation, 87% for the learning process, and 86.75% for practicality. The overall percentage across all indicators was 87.33%, placing it in the "Very Good" category for use in the Basic Electrical Energy Practicum.

Keywords: Digital twin; Distance learning; Practicum; Technology

Introduction

Education in the current era emphasizes the cultivation of 21st-century skills, which encompass three core dimensions: cognitive skills, behavioral competencies, and the ability to navigate real-world contexts (Mirna et al., 2025). However, the online implementation of practicum courses has not been optimal in providing students with practical experience, despite the fact that practicums are intended to develop soft skills aligned with the demands of Outcome-Based Education (OBE) as promoted by the government and academic institutions. Therefore, it becomes the responsibility of educators to design and facilitate conducive learning environments that can support the achievement of these intended learning outcomes (Fatimatuzzahro & Ahmad, 2025). This urgency is reinforced by the onset of the Industrial Revolution 4.0, characterized by the fusion of physical, and digital spaces that are gradually shifting human activities from manual to digital processes (Dewi et al., 2024). During the COVID-19 pandemic, remote practicum courses were conducted using software-based simulations. In 2020, the COVID-19 pandemic caused many applied aspects and experiential components of practicum activities to shift from 'real-world' experiences to virtual and 'remote' contexts. This article highlights insights from students enrolled in global public health undergraduate programs who had initially planned real and more traditional' practicum experiences, but were required to transition to 'remote' and online engagement. These cases indicate that participation in virtual practicum sites is regarded as legitimate, fulfilling for both students and stakeholders, and can enhance diversity, equity, and inclusion in public health curricula, while also promoting best practices in career development (Upton, 2025). The challenges faced during the pandemic, which required practicums to be conducted remotely, prompted the development of solutions that enable laboratory practicums to be accessed from anywhere. In line with this, productive subjects are designed to prepare students to face real-world business challenges and adapt to the dynamic needs of the industry (Deliana & Anwar, 2025).

Some of the solutions that have already been implemented for remote practicums at various

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universities include remote laboratory-based practicums and the "kitchen chemistry experiment" method, which utilize virtual laboratories, have emerged as alternative solutions for vocational school practicum activities. These approaches address common challenges faced by educational institutions, such as inadequate laboratory facilities, limited equipment, lack of maintenance staff, and constraints related to space and time, which often hinder the effective implementation of the learning process (Karunianto & Saputro, 2017). In addition to existing media previously utilized for remote practicums, this study introduces an innovative approach by implementing digital twin technology as a remote practicum tool. This innovation aligns with teachers' positive attitudes toward Information and Communication Technology (ICT) and their ongoing efforts to integrate technological advancements into education (Dadang et al., 2025). Digital Twin technology is projected to integrate with other advanced technologies such as augmented reality (AR) and artificial intelligence (AI) to enable deeper connections, richer insights, and enhanced analytics (Attaran & Celik, 2023). These developments align with the role of learning media as intermediaries that deliver information effectively, aiming to improve learning outcomes, boost student motivation, and facilitate more comprehensive and meaningful educational experiences (Maulidya & Astuti, 2025).

Digital twin technology makes the production process more effective and efficient because it allows a person to control tools and machines remotely, eliminating the need to be physically present on site. Currently, digital twin technology is already being applied in industries such as manufacturing, transportation, energy, and healthcare. In the industrial sector, digital twin technology can simulate industrial processes to find the best solutions when problems arise. With this technology, machine problems can be detected quickly through quantitative data sent by sensors. In the healthcare sector, digital twin technology is used for rapid remote patient monitoring. With this technology, patients do not need to be transported to hospitals by ambulance; instead, doctors can monitor patients remotely and provide immediate assistance. Digital twin is facilitated by advanced data analytics and utilizes Internet of Things (IoT) connectivity. IoT technology has been widely applied to enhance the capacity and control of company manufacturing production, healthcare, and smart cities. IoT offers a wide range of applications, especially when combined with the necessary data for analysis, thereby providing essential outcomes for maintenance, predicting company manufacturing processes, detecting potential human health anomalies or disorders, urban development, managing traffic in smart cities, as well as being applicable to classroom management in the field of education (Permana, 2021).

Since digital twin technology is already being applied in other sectors, the researcher attempts to design and implement it in the field of education—specifically as a distance learning medium for the Basic Electrical Energy Practicum course, focusing on the topic of solar panel characteristics. The implementation of digital twin technology in practicums can facilitate students in operating laboratory equipment because a digital twin is a virtual model of a physical machine asset replicated on a computer model. Thus, it represents an integration between hardware and software, physics and machine learning. Digital twins can provide insights into what might happen, what is happening, and what will happen in the system (Fuller et al., 2020). The purpose of this study is to determine the feasibility and user responses to the use of digital twin technology for remote practicums in the Basic Electrical Energy Practicum course.

Previous research related to this study includes Delussu in "Experiments and Comparison of Digital Twinning of Photovoltaic Panels by Machine Learning Models and a Cyber-Physical Model in Modelica." Their study applied the digital twin concept by combining two methods. In the first method, the Open Modelica software was used to simulate the physical parameters of a solar panel. In the second method, the solar panel modeling was based on field data collected using machine learning techniques. Both models were provided with the same weather data, and the results were compared. After comparison, the two methods were combined to leverage the strengths of each model. Although this study applied the digital twin concept to solar panels, it did not involve controlling or managing a physical solar panel directly; the authors only monitored and controlled a simulated solar panel model built from periodic data obtained from a solar panel at a specific location (Delussu et al., 2022).

Another relevant study is by Nurmayanti (2021) titled "Utilization of the TeamViewer Remote Desktop Application in Remote Practicums at Vocational High School 5 Sidrap," which showed that remote practicums for the Basic Programming subject were successfully carried out. The observation results showed a 100% success rate both for practicum implementation and for the use of the TeamViewer remote desktop application (Nurmayanti, 2021). Shelin et al. (2021) in their study "Development of an Online Practicum Guide Using the Smartphone-Based Phypox Application," recommended the use of the Phypox app on smartphones for pendulum material as a viable option to optimize practicum activities in the physics department, either through blended learning or independent study at home. Since 2020, with the emergence of the

Coronavirus Disease 2019 (Covid-19) pandemic, learning has had to shift from face-to-face instruction to distance learning, also known as online learning (Sadikin & Hamidah, 2020). During the Covid-19 period, the learning process in higher education for both theoretical and practical courses was carried out remotely. This was done to prevent physical interaction between students as well as between students and lecturers (Kusumaningrum & Wijayanto, 2020). Based on the results of a survey on the effectiveness of online learning during the Covid-19 pandemic in higher education conducted by Hikmat et al. (2020), it was shown that practicum learning obtained a lower effectiveness score compared to theoretical learning. Raffi Erba in "Development of a Remote Laboratory-Based Basic Electrical Energy Practicum Module as a Distance Learning Medium," found that the feasibility of the logic gate practicum module using a remote laboratory was categorized as very good, with very positive user responses, scoring 86.74% (Erba, 2021). Fina Khaerunnisa in "Implementation of Remote Practicum on Microbial Growth Topics During the COVID-19 Emergency at the Sumatera Institute of Technology," found that using daily chemical materials in practicums yielded positive results. Among 92 students, 91.3% agreed that the practicum material aligned with classroom learning. The evaluation showed that 88% of students could conduct observations effectively, 86% felt that at-home practicums were easier and more practical than laboratory ones, and 83% of students achieved high scores, indicating a good understanding of the material (Khaerunnisa et al., 2020). "There are also those who have developed virtual laboratories for practicum activities in vocational high schools. This study has already implemented a virtual laboratory for a biology simulator, where experimental activities can be carried out just like in a real laboratory. The virtual laboratory can be accessed using smartphones and laptop (Jaya, 2012).

From the relevant previous studies, there is a noticeable difference compared to the research being conducted here. The primary difference—or gap analysis—lies in the learning media used. Existing media for remote practicums includes the TeamViewer Remote Desktop Application, the smartphone-based Phypox app, remote laboratories, and daily chemical experiments. In contrast, this study seeks to design and implement digital twin technology as a new form of remote practicum media.

Method

Quantitative research is a systematic approach to gaining a comprehensive understanding of social realities, requiring careful attention to various issues that may arise (Rahma & Suratno, 2024). It involves collecting, analyzing, and interpreting quantifiable data to test hypotheses and generate generalizable findings from a study sample across varied perspectives (Ghanad, 2023). In line with this, the present study employs the Research and Development (R&D) method, which generally follows a ten-stage research design (Sugiyono, 2003), but this study only implements the following stages: identifying potential and problems, data collection, product design, design validation, usage trials, product revision, and product testing. Basically, innovation activities are strongly tight into the concept of research and development (Kainulainen, 2014). The research flowchart in Figure 1 illustrates the design of digital twin technology as a distance learning medium for the Basic Electrical Energy Practicum course.

During the data collection stage, the objectives of developing the remote practicum learning media for the Basic Electrical Energy Practicum course were determined, as well as the gathering of material on the characteristics of solar panels, including the tools and materials required.

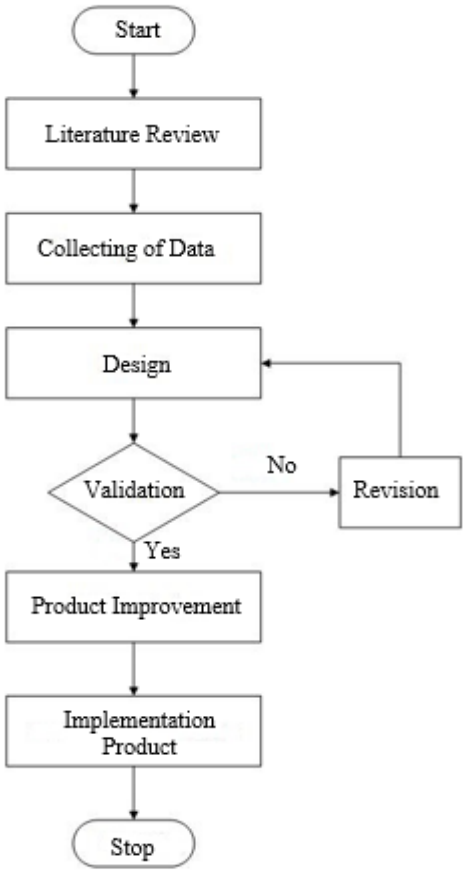

Figure 1. Flowchart of research

The research was conducted in the Electrical Engineering Education Department at Universitas Islam

Negeri (UIN) Ar-Raniry Banda Aceh. The research period spanned from February 2023 to August 2023. The sampling technique used in this study was convenience sampling, involving 20 students from the Electrical Engineering Education program. This relatively small sample size was selected due to the study's limited-scale design stage, aiming for initial feasibility and user response testing.

The instruments used in this study were validation sheets and questionnaires. The validation sheets were used to assess the feasibility of the digital twin technology by both media experts and subject matter experts. This process ensures content validity, which refers to the extent to which the measurement tools accurately represent the constructs being evaluated (Zakiyah et al., 2024). The questionnaires were used to gather user responses to the digital twin technology. The questions in the validation and questionnaire instruments were in multiple-choice format, with a scoring scale from 1 to 5.

The indicator grids for the validation sheets and user response questionnaire are presented in the following tables.

Table 1. Indicator grid for media expert validation questionnaire

Indicator	Statement
System	1; 2; 3; 4; 5; 6
User	7; 8; 9; 10
Navigation	11; 12; 13
Usage Instruction	14

Table 2. Indicator grid for subject matter expert validation questionnaire

Indicator	Statement
Content Relevance	1; 2; 3; 4; 5; 6; 7
Learning Process	8; 9; 10; 11; 12; 13; 14

Table 3. Indicator grid for user response questionnaire

Indicator	Statement
Content Relevance	1; 2; 3; 4
Learning Process	5; 6; 7; 8
Practicality	9; 10; 11; 12

After the data is collected, the mean value will be calculated using the formula:

$$\bar{X} = \frac{\sum x}{n} \quad (1)$$

Where:

$\bar{X}$: Average score
$\sum x$: Total score
n : Number of responden

Once the average score is obtained, it will then be converted into feasibility categories using the conversion guidelines shown in Table 4 (Sukardjo, 2005).

Table 4. Score conversion guidelines

Formula	Category
$X > X_i + 1.8SB_i$	Very Feasible
$X_i + 0.6SB_i < X < X_i + 1.8SB_i$	Feasible
$X_i - 0.6SB_i < X < X_i + 0.6SB_i$	Fair
$X_i - 1.8SB_i < X < X_i - 0.6SB_i$	Less Feasible
$X \leq X_i - 1.8SB_i$	Very Less Feasible

Result and Discussion

Result

The remote practicum learning developed in this study is focused on the Basic Electrical Energy Practicum course, which serves as a foundational subject in the Electrical Engineering Education study program. The product developed is a digital twin for virtual and simulation purposes that can support practicum activities. Based on a needs analysis conducted through a survey on the implementation of online practicum in the Electrical Engineering Education Program at the Faculty of Tarbiyah and Teacher Training, UIN Ar-Raniry, two main indicators formed the basis for developing this practicum tool. These indicators are closely aligned with the crucial role of teaching practicum in preservice teachers' professional development, as it significantly shapes their beliefs and perceptions toward teaching (Imsa-ard et al., 2021).

The first indicator relates to the challenges and difficulties faced by students in carrying out practicum courses online. Most responses indicated that the biggest difficulty in virtual practicum sessions was the limited availability of virtual lab media or online practicum simulations used as alternatives to the physical tools found in laboratories. These limitations stem from restricted access to free online simulation media or the lack of complete practicum material/topics available.

Moreover, students noted that online simulation media failed to provide a meaningful scientific observation experience. The second indicator, which further justified the development of this digital practicum module, concerns the importance of having interactive virtual technology in the implementation of online lectures in the Electrical Engineering Education program. Approximately 70.3% of the total respondents stated that the use of digital twin technology in remote practicum is highly important to support virtual learning. Not only does it help enhance the effectiveness of the learning process, but it also appears to increase student motivation during online practicum sessions. Based on this needs analysis evaluation, a digital twin was then developed to support the implementation of

the Basic Electrical Energy Practicum course, specifically on the topic of solar panel characterization.

The designed digital twin technology was then tested for validity in terms of both media and content. The media and instructional design assessment focused on the system, user interface, navigation, and usage instructions within the digital twin platform to support remote practicum learning. The content assessment focused on the relevance of the practicum topic displayed in the digital twin-based learning media with the curriculum content of the Basic Electrical Energy Practicum course. Additionally, it evaluated the depth of the material and the learning process using digital twin technology on the topic of solar panel characteristics.

The result of the digital twin technology design for remote practicum in the Basic Electrical Energy course, specifically for the solar panel characteristics topic. The designed digital twin technology consists of several components integrated into a single panel box. This integration is intended to make it easier to place next to the solar panel, which is connected by cables. The components inside the panel box can be seen in Figure 2.

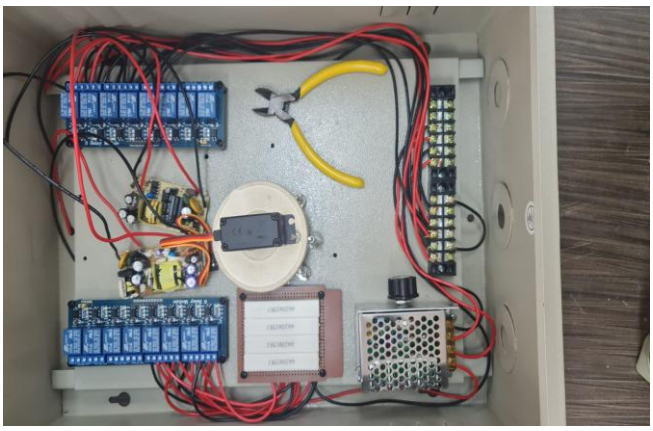

Figure 2. Components Inside the panel box for digital twin technology

The display results shown on each user's screen are illustrated in Figure 3. Once the digital twin technology was successfully designed, the next step was to validate the learning media with experts. In this study, the validation results of the digital twin technology for remote practicum in the Electrical Energy Basics practicum course were obtained through a validation questionnaire completed by four experts. The four selected experts for validating the feasibility of the digital twin technology as a distance learning medium in the Electrical Energy Basics practicum course are lecturers with knowledge and experience in their respective fields. During the validation process, the experts were asked to assess specific aspects of the digital twin technology, such as feature completeness, display clarity, and ease of use. Once completed and collected, the validation questionnaires were analyzed to determine the feasibility of the digital twin technology for remote practicum in the Electrical Energy Basics practicum course.

The validation of the digital twin technology for remote practicum in the Electrical Energy Basics practicum course was conducted by Mr. Baihaqi, M.T., and Mr. Mursyidin, M.T., on July 15, 2023. The purpose was to obtain feedback, critiques, and suggestions from the validators regarding the digital twin technology for remote practicum in the Electrical Energy Basics practicum course, particularly in terms of its function as a learning medium. This aims to ensure that the trainer meets the media feasibility requirements and can be further developed into a high-quality learning medium. To evaluate the feasibility of the digital twin technology for remote practicum in the Electrical Energy Basics practicum course, a validation was carried out by providing an assessment questionnaire to the validators. The questionnaire contained 14 items evaluating various aspects of media feasibility, such as system quality, user experience, navigation, and user guidance. This media validation was conducted to ensure that the digital twin technology for remote practicum in the Electrical Energy Basics practicum course possesses good quality media and has the potential to be developed into an effective and high-quality learning tool. Additionally, its integration with online simulations may influence students' satisfaction and their perceptions of learning effectiveness (Ari et al., 2022). The results of the media validation feasibility test are presented in Table 5.

Table 5. Media validation feasibility test results

Validator	Total Score	Average (%)
Media Expert 1	65	92.86
Media Expert 2	62	88.57
Total Average		90.71

Based on Table 5, it can be seen that the results of the media feasibility validation by media expert validators show that the digital twin technology for remote practicum in the Electrical Energy Basics practicum course received a percentage of 92.86% from Media Expert 1 and 88.57% from Media Validator 2. Therefore, the average score obtained for media validation was 92.86%, which falls into the 'very valid' category. Hence, it can be concluded that the digital twin technology for remote practicum in the Electrical Energy Basics practicum course is feasible to be used as a learning medium in the form of technology for the Electrical Energy Basics practicum course.

The content validation of the digital twin technology for remote practicum in the Electrical Energy Basics practicum course was conducted by Mr. Muhammad Ikhsan, M.T., and Mr. Muhammad Rizal

Fachri, M.T., on July 17, 2023. The purpose was to obtain feedback, critiques, and suggestions from the validators regarding the digital twin technology for remote practicum in the Electrical Energy Basics practicum course, particularly in terms of content. The validation focused on the subject matter of solar panel characteristics and was carried out by two subject matter experts with relevant knowledge and experience in the field. This aims to ensure that the trainer meets the content feasibility requirements and can be further developed into a high-quality learning medium aligned with the curriculum of the Electrical Engineering Education Study Program. To evaluate the feasibility of the digital twin technology for remote practicum in the Electrical Energy Basics practicum course, validation was conducted through an assessment questionnaire given to the validators. The questionnaire contained 14 items evaluating various aspects of content feasibility, such as content relevance and instructional alignment. This content validation was conducted to ensure that the digital twin technology for remote practicum in the Electrical Energy Basics practicum course has good media quality and can be developed into a high-quality learning medium in terms of content. The results of the material validation are shown in Table 6.

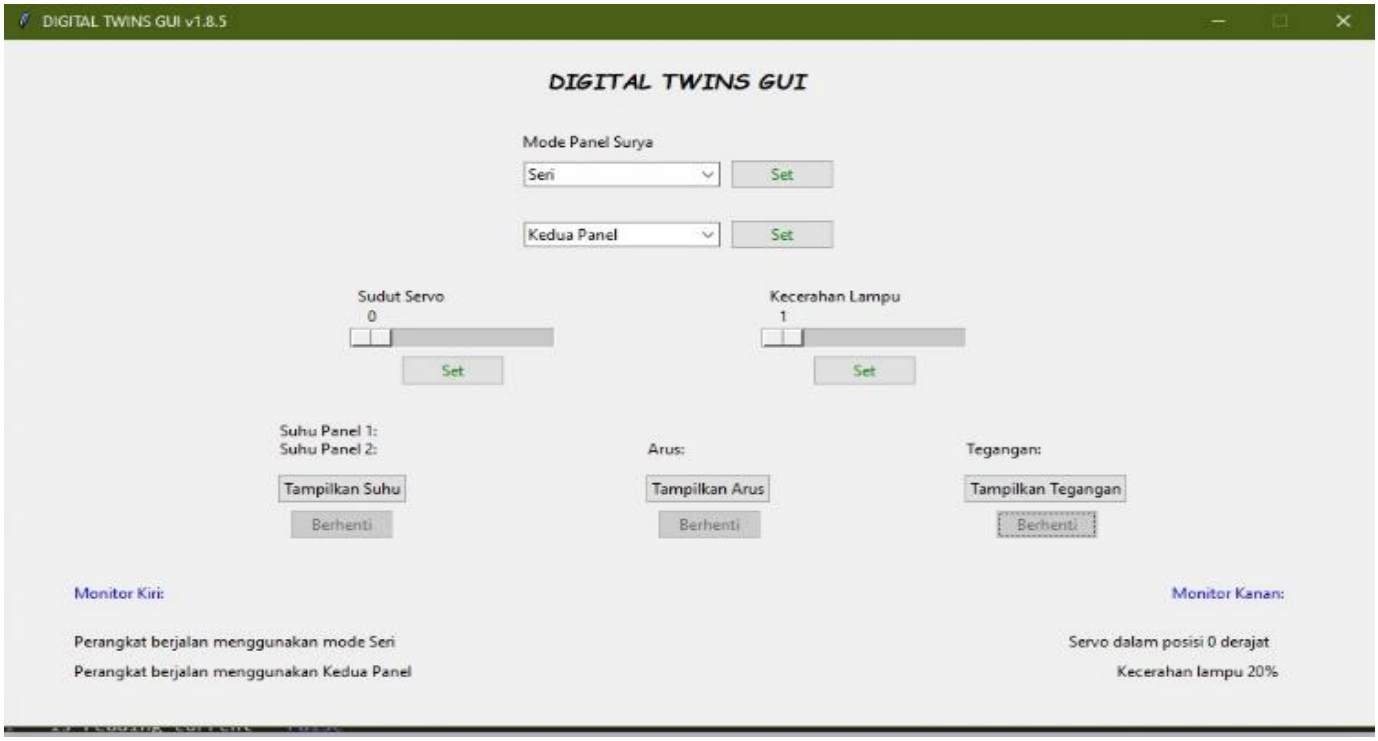

Figure 3. Display results on the user's monitor screen

Table 6. Content validation feasibility test results

Validator	Total Score	Average (%)
Content Expert 1	63	90.00
Content Expert 2	64	88.57
Total Average		91.43

Based on Table 6, it can be seen that the results of the content feasibility validation by subject matter expert validators show that the digital twin technology for remote practicum in the Electrical Energy Basics practicum course received a score of 90% from Subject Matter Expert 1 and 92.86% from Subject Matter Expert 2. Thus, the average score obtained for content validation was 91.83%, which falls into the 'very valid' category. Therefore, it can be concluded that the digital twin technology for remote practicum in the Electrical Energy Basics practicum course is feasible to be used as a learning medium in the form of technology for the Electrical Energy Basics practicum course.

The validation data collected from both media and content experts is illustrated in Figure 4, which shows the validation results for the media and content used in the study.

Based on Figure 4, it is evident that the digital twin technology for remote practicum in the Basic Electrical Energy Practicum course has undergone a validation process by both media and content experts. The media validation received an average score of 90.71%, while content validation received 91.43%. Therefore, overall, the digital twin technology qualifies as highly feasible for application in this practicum course, both in terms of media and content. The validation process provides confidence that this technology can effectively convey

learning material in an understandable manner, supported by suitable media design.

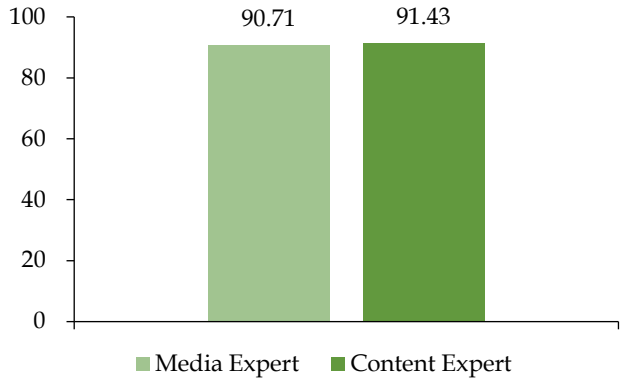

Figure 4. Expert validation results

The product trial aimed to assess how important the digital twin technology is perceived by students. The limited trial involved 20 students from the Electrical Engineering Education Program at UIN Ar-Raniry. The evaluation was divided into three indicators: Relevance of the content presented in the digital twin with the materials taught in class; Learning process experienced by students while using the digital twin; and Practicality in terms of content delivery and practicum implementation.

The trial was conducted by the researcher demonstrating the usage and operation of the digital twin. At the end of the session, students were asked to complete a response questionnaire. The results of the product trial are shown in Table 7.

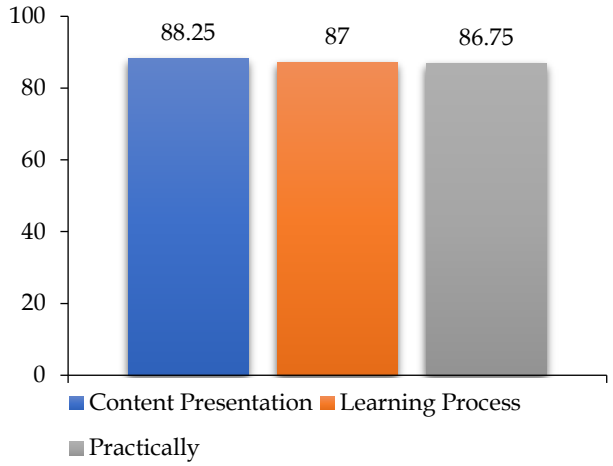

Figure 5. User response per indicator

After analysing the student responses, the average score reached 94.32%. This percentage indicates that the use of digital twin technology is considered "highly feasible" as a learning medium and applicable for use in delivering the practicum content. The positive feedback shows that this technology can significantly enhance the learning quality of the Basic Electrical Energy Practicum, especially by making it easier to understand complex concepts such as solar panel characteristics, even when taught remotely. The student response data is visualized in Figure 5.

Table 7. Student response results

Indicator	Score per Indicator (%)
Content Presentation	88.25
Learning Process	86.67
Practicality	87.50
Total Average	94.32

The results of the validity test calculations for each instrument are presented in Table 8 as follows.

Table 8. Validity test results of the respondent questionnaire instrument using SPSS program

Kaiser-Meyer-Oikin Measure of Sampling Adequacy		0.70
Bartlett's Test of Sphericity	Apprix. Chi Square	61.84
	df	10
	Sig.	0.00

Based on the calculation results from SPSS version 22.0, the KMO value obtained was 0.70 (> 0.5). The Bartlett's Test of Sphericity showed a significance value of 0.00 (< 0.05). This indicates that the instrument used can be declared valid and is suitable for use in research with a larger sample size.

The results of the reliability test using SPSS version 22 showed that the reliability score of user responses to the digital twin technology for remote practicum in the Electrical Energy Basics practicum course had a Cronbach's alpha value of 0.753, as shown in Table 9.

Table 9. Reliability test results of the user response instrument using SPSS program

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.73	0.75	12

The overall Cronbach's alpha value for the internal factor items was 0.753, indicating that all items are reliable. The overall reliability level is categorized as high, with a value of 0.753 within the interval range of 0.60–0.799. The results of the normality test using SPSS 22.0 are shown in Table10.

Based on Table 10, the normality test results using the Shapiro-Wilk test indicate that the variable "content presentation" has a significance value of 0.015 (< 0.05), thus Ho is rejected. The significance value for the "learning process" variable is 0.075 (> 0.05), and for the "practicality" variable it is 0.55 (> 0.05), meaning that for

the user response toward the digital twin technology, Ho is accepted. Therefore, it can be concluded that the data distribution for user responses to the digital twin technology for remote practicum in the Electrical Energy Basics practicum course is normal.

Table 10. Normality test results using SPSS program

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Presentation of material	.150	51	.006	.942	51	.015
Learning process	.134	51	.023	.959	51	.075
Practicality	.085	51	.200*	.980	51	.555

*. This is lower bound of the true significance.
a. Lilliefors significance correction.

Discussion

The main objective of this research is to determine the feasibility level and user response results toward the use of digital twin technology for remote practicum in the Basic Electrical Energy Practicum course. This digital twin technology is expected to help students understand the course material virtually, making the practicum learning process easier and more effective. Furthermore, by developing a valid and practical digital twin, it is hoped that this technology can improve the quality of learning and provide students with a better learning experience. Therefore, this study offers significant benefits in enhancing the quality of remote practicum learning, particularly in the Basic Electrical Energy Practicum course.

The digital twin technology for remote practicum in this course has undergone validation by media and content experts. In media testing, media experts gave a percentage score of 90.72%, while the material validation resulted in a score of 91.43%. Therefore, overall, the digital twin technology is categorized as highly feasible to be implemented in the Basic Electrical Energy Practicum course, both in terms of media and content. The validation by media and content experts confirms that the digital twin technology is capable of delivering accurate and comprehensible material with the support of appropriate media. Thus, it can be considered a suitable option for helping students better understand the concept of solar panel characteristics, even when the practicum is conducted remotely. In addition, the use of interactive digital media can serve as an effective pedagogical tool to support students' comprehension of subject matter delivered in class, thereby enhancing conceptual understanding and engagement (Armiyati & Asih, 2025).

This is supported by research from Hutahaean et al. (2019), which states that interactive e-modules developed by integrating two or more media (text, graphics, images, audio, video, or animation) can create a two-way interaction between the module and the user, motivating students to be active, creative, and independent in learning. A similar statement is presented by Hockicko et al. (2015), who explain that video-based experiments help students understand scientific principles and phenomena more deeply, develop abstract thinking skills, and foster curiosity about the world and nature. Gunawan et al. (2019) also added that students' skills are formed through direct interaction with virtual lab activities conducted repeatedly to find answers to the investigated problems. Through home-based practicum activities integrated into this digital practicum module, students are given the opportunity to conduct experiments directly, which encourages them to sharpen and develop several scientific skills such as formulating objectives, conducting experiments, preparing tools and materials, and collecting data (Iradat, 2017).

In a limited-scale trial, the overall percentage score for all indicators was 87.33%, placing user responses to the importance of digital twin technology for remote practicum in the Basic Electrical Energy Practicum course in the "Very Good" category, especially for the topic of solar panel characteristics. Based on the responses from students, it can be concluded that the use of digital twin technology as a remote practicum learning medium has the potential to improve learning outcomes. Students responded positively to the operation of the digital twin and the clarity of the delivered material. Although certain factors might affect the efficiency of learning time, the digital twin technology still helps students to understand the material effectively.

Therefore, the use of digital twin technology can serve as an effective alternative solution for enhancing the quality of practicum learning outcomes. Moreover, the quality of learning is not solely dependent on technology but is also supported by instructional approaches such as project-based learning and inquiry-based learning, which emphasize students' experimental and investigative abilities (Kusumadani et al., 2025). Research of Aswan et al. (2024) show results indicate a significant difference between studentspretest and posttest scores in critical thinking ability, suggesting that PjBL is effective in enhancing critical thinking skills, there is a significant difference between the pretest and posttest scores of students' critical thinking abilities. It can be concluded that PjBL is effective in improving critical thinking skills (Aswan et al., 2024). The inquiry learning model engages students in situations that stimulate questioning, hypothesis development, and knowledge construction until they reach a comprehensive understanding of a concept. Previous studies by researchers and practitioners have

demonstrated that this model enhances students' cognitive, psychomotor, and affective learning abilities. The present study confirms the significant impact of systematic inquiry-based instruction on students' learning. Quantitative findings indicate that the inquiry learning model effectively improves science process skills and overall learning outcomes. However, its implementation still requires further optimization to maximize its potential in advancing the quality of education (Fahmi et al., 2024). The research of Istiyati et al. (2024) show that study indicates notable variations in teachers' competencies in implementing differentiated learning in Surakarta. While many teachers excelled in using learning media and improving their practices—falling into the Very Satisfactory and Outstanding categories—challenges remain in assessing student progress and applying differentiated strategies. The findings highlight the need for continuous professional development, particularly in assessment and strategy implementation. This technology enables monitoring, analysis, and simulation of physical entities, providing valuable insights and opportunities for optimization and improvement (Jankovskis et al., 2024). These insights can be further enhanced through data analysis using appropriate measurement tools that align with the observed phenomena. Additionally, the application contains features that not only facilitate but also provide opportunities for students to perform more in-depth data analysis. The use of the tracker application in this digital practicum module motivates students to actively engage in learning activities. This aligns with the findings of Aththibby & Kuswanto (2021), who emphasize that through video analysis of real experiments, students gain authentic experiences in conducting experiments, analyzing graphs, and identifying motion equations like scientists. Learning becomes easier and more enjoyable for students. It is highly recommended that teachers identify students' misconceptions about motion or other physics concepts and implement remediation using video analysis of real experiments conducted by the students themselves.

Conclusion

The conclusion that can be drawn from this study is that the feasibility results of digital twin technology for remote practicum in the Basic Electrical Energy Practicum course—specifically in teaching solar panel characteristics—received a percentage score of 90.71% from media experts and 91.43% from content experts. Based on these validation results, the digital twin-based media was categorized as "Highly Feasible" for implementation in remote practicum activities to enhance students' understanding of solar panel behavior in the context of electrical energy learning. Student responses to the use of digital twin technology for remote practicum in the Basic Electrical Energy Practicum course demonstrated a strong positive perception across key indicators, reflecting the media's effectiveness in presenting material, supporting learning processes, and ensuring practicality. These findings suggest that digital twin technology is not only feasible but also well-received by students, reinforcing its potential as an innovative tool for enhancing understanding of solar panel characteristics in remote practicum settings. This aligns with the research objective of improving practicum quality through accessible, interactive, and simulation-based learning environments. The findings from this study, including high feasibility ratings and strong student responses, demonstrate that digital twin technology effectively addresses the research objective of enhancing the quality and accessibility of remote practicum experiences—particularly in teaching solar panel characteristics. By leveraging its strengths and addressing its limitations, educators and policymakers can design more effective educational policies and teacher training programs to support comprehensive competency development specifically in digital technology use. The results of this study highlight the strong feasibility and positive reception of digital twin technology in remote practicum settings, particularly for teaching solar panel characteristics. These findings imply that digital twin-based learning tools can serve as a viable solution to overcome resource limitations in vocational and technical education. Policymakers and educators are encouraged to integrate such technologies into curriculum design and teacher training programs to promote digital competency and improve practicum quality.

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The authors declare no conflict of interest.

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