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kWh Meter Trainer Design for Electrical Installation Engineering Practicum

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Abstrak

Understanding the operating principles, installation, and measurement of electrical energy using a kWh meter is a crucial competency in Electrical Installation Engineering education. However, limited practical equipment in laboratories can hinder the implementation of safe, contextual learning. This study aims to develop a portable, safe, simple, and user-friendly kWh meter trainer to serve as a practical learning aid. The study employs the Research and Development (R&D) method using the 4D model, comprising the define, design, develop, and disseminate stages. Product feasibility was evaluated through validation by design and media experts using a Likert scale instrument. Validation results indicated a feasibility score of 84% from the design expert and 89% from the media expert; both ratings fall into the "highly feasible" category. These results demonstrate that the developed trainer meets design and media feasibility standards for supporting practical training in kWh meter installation and electrical energy measurement. This kWh meter trainer can serve as a supporting tool for practical learning in Electrical Installation Engineering laboratories. Further research is needed to assess the trainer's practicality and effectiveness regarding student learning outcomes and skill acquisition.

Keywords: *Tainer, kWh Meter, Electrical Installation Engineering, Learning Media*

Abstrak

Pemahaman mengenai prinsip kerja, pemasangan, dan pengukuran energi listrik menggunakan kWh meter merupakan kompetensi penting dalam pembelajaran Teknik Instalasi Listrik. Namun, keterbatasan peralatan praktik di laboratorium dapat menghambat pelaksanaan pembelajaran yang kontekstual dan aman. Penelitian ini bertujuan untuk mengembangkan trainer kWh meter yang portabel, aman, sederhana, dan mudah digunakan sebagai media pembelajaran praktik. Penelitian menggunakan metode *Research and Development* dengan model 4D yang meliputi tahap pendefinisian, perancangan, pengembangan, dan penyebaran. Kelayakan produk dievaluasi melalui validasi ahli desain dan ahli media menggunakan instrumen skala Likert. Hasil validasi menunjukkan persentase kelayakan sebesar 84% oleh ahli desain dan 89% oleh ahli media; keduanya berada pada kategori sangat layak. Hasil tersebut menunjukkan bahwa trainer yang dikembangkan telah memenuhi aspek kelayakan desain dan media untuk mendukung praktik pemasangan serta pengukuran energi listrik menggunakan kWh meter. Trainer kWh meter ini dapat digunakan sebagai media pendukung pembelajaran praktik di laboratorium Teknik Instalasi Listrik. Penelitian lanjutan perlu menguji kepraktisan dan efektivitas trainer terhadap hasil belajar serta keterampilan siswa.

Kata kunci: *Tainer,* kWh Meter, Teknik Instalasi Listrik, Media Pembelajaran

Introduction

Education is very important because it plays a big role in the development of a country [1]. Education is a deliberate effort to realize the process of passing on values and culture from one generation to the next. Through education, the current generation is formed as role models based on the teachings and experiences of the previous generation [2]. Learning media influences changes in teaching methods because it is part of the learning resources that support students in developing their various potentials and understanding the material more deeply. Learning media is an integrated element in the entire learning system and process. This means that media not only functions as a tool to assist teachers in delivering material but also as a key factor in determining the success of the learning activity itself [3], [4]. This situation also causes many students to struggle to understand the material in Electrical Installation Engineering courses. This poor understanding results in less than optimal learning outcomes, particularly in installation competencies. Students now understand learning more easily through Project-Based Learning because they can engage directly with the material.

A trainer is a learning resource that presents or demonstrates the characteristics of the concepts students learn during the educational process. By using a trainer, students are expected not only to memorize and observe the available tools but also to directly apply or assemble the components of those tools, thus improving their understanding of the material [5], [6]. Electricity use in daily activities is increasing along with technological developments and the increasing needs of today's society. To ensure efficient electricity use and compliance with applicable regulations, electricity measurements are necessary using a kWh meter. This device records a user's energy consumption in kilowatt-hours (kWh), which is the basis for determining electricity costs by PLN [7], [8]. In addition to serving as a learning aid, this kWh meter training tool is also used to evaluate students' skills in installation, calibration, and reading electrical energy consumption data. The kWh meter training tool is an effective learning alternative because it provides hands-on experience in the installation and working principles of this measuring instrument in a safer and more controlled environment [9].

A kWh meter is one of the electrical devices that cannot be separated from the negative impacts generated by harmonics. Accurate electrical energy readings are very important to attract the attention of both consumers and electricity providers. A kWh meter functions as an energy measuring tool used to calculate electrical power. Simply put, a kWh meter functions to find out how much electrical energy is used in a certain period of time, not just the amount of power at a certain time. The information displayed by the kWh meter is used by electricity providers and users to monitor electrical energy usage, so that electricity use can be controlled and carried out more economically and efficiently. Electricity is a crucial human need and a key economic resource. In the future, demand for electricity will increase along with technological advances. Electricity plays a vital role in everyday life, including in households, lighting, communications, industry, and more [11], [12]. In the world of electricity, an electrical installation consists of various electrical devices interconnected within a single power system. Electrical installations are essential and indispensable in today's daily life. Electrical installations are commonly used in locations such as homes, offices, and factories. However, the reliability of an

electrical installation can be affected by many factors, such as the selection of inappropriate equipment or poor installation quality [13].

Recent studies in engineering education emphasize that trainer kits can simplify circuit implementation and provide an efficient platform for laboratory learning [21]. Engineering laboratories remain important for developing practical, design, measurement, and problem-solving competencies [22]. Comparative reviews of hands-on, simulated, virtual, and remote laboratories indicate that each format supports different learning objectives; therefore, physical trainers are particularly relevant when students need direct experience with components, wiring, safety, and measurement [23]-[26]. Project-based learning in higher education and engineering has also been associated with stronger engagement, collaboration, problem solving, and the application of knowledge to authentic tasks [27], [28]. Remote-laboratory research further shows that clear instructions, active learning, feedback, and structured experimental activities are important for supporting student engagement and the transfer of theory into practice [29], [30].

This study aims to design and realize a kWh meter trainer as a learning tool in the Electrical Installation Engineering Practice at UIN Ar-Raniry Banda Aceh. This study focuses on the development of the trainer design, the level of accuracy of electrical energy measurements, and the effectiveness of the tool in supporting electrical practical learning activities. It is hoped that the existence of this trainer can be an innovative alternative that contributes significantly to improving the quality of Electrical Engineering Education. Regarding the tools for Electrical Installation in the Electrical Engineering Education Study Program at UIN Ar-Raniry Banda Aceh, the trainer is intended to function and provide benefits. This tool acts as a reminder to install electrical installations in the right position during installation in the field, this is very useful for skills in installing kWh meters.

Method

According to research [14], this study was initiated by identifying existing potentials and problems. Potential is defined as any resource or condition that can generate added value when properly utilized. Likewise, a problem may also be transformed into a potential when it is addressed and managed effectively. Observations conducted in the Department of Electrical Engineering Education at UIN Ar-Raniry, Banda Aceh, revealed a limited availability of learning references to support instructional activities in the electrical laboratory. In addition, students encountered difficulties in understanding kWh meter concepts and their applications in the learning process. From the identified potential and problems, an effort was made to design a learning media in the form of a trainer in the Electrical Installation course into a Trainer Presentation in the Department of Electrical Engineering Education, UIN Ar-Raniry, Banda Aceh, as a reference.

The research procedures described can be carried out more effectively if supported by a development model. This study uses the Research and Development (R&D) method with the applied development model being the 4D model. The process of this development model includes the stages of Define, Design, Development, and

Disseminate. For this study, the development design used follows the research and development procedures according to the 4D development model, which consists of four stages: define, design, development, and disseminate, which have been adapted and modified [15], [16].

Defining Stage, the results of the interview found obstacles in the electrical installation engineering practicum course which was based on the research from the defining step, information was obtained regarding the analysis of instructional needs which showed that the learning media needed as support or practical aids for the electrical installation engineering course were still not available. Meanwhile, the analysis of student needs showed that the attitude of caution during the practicum and the students' interest in learning were still low, so it was necessary to develop learning media in the form of a trainer. Planning Stage (Design), product design is the initial representation of the electrical installation training device that will be used as a learning tool for the electrical installation engineering course. This learning aid is designed to be portable and simple so it can be easily moved. This is due to the fact that laboratory practice will be moved [6].

In the development stage, the design created in the design stage is then realized into a real product in the form of a kWh Meter trainer. After the product is completed, the trainer is then validated by media experts and material experts. This validation process aims to assess the feasibility of the trainer in terms of appearance, function, safety of use, and suitability of the material with the learning outcomes in the Electrical Installation Engineering course. The results of this validation are used as material for improvements and refinements, so that the developed trainer is truly suitable for use as a learning medium in practical activities [17].

Dissemination stage, the design stage is the process of creating a cover and trainer design based on the Electrical Installation Engineering practical course and input from the supervising lecturer. At the end of this design stage, a layout design for the trainer is obtained. The trainer layout is made using acrylic material which is then equipped with stickers as the identity of the components. The manufacturing process is adjusted to the size of the components contained in the trainer. The dimensions for the trainer box are with specifications of 20 cm wide and 30 cm long [18], [19].

The testing of the kWh Meter demonstration tool was conducted through two validation aspects, namely media validation and design validation. This validation process involved four expert lecturers on campus, where two lecturers acted as media expert validators and two other lecturers as design expert validators. The purpose of the media validation test was to determine whether the kWh meter demonstration tool was suitable for use in the learning process, especially for students taking the Electrical Installation Engineering course, seen from the aspects of appearance, component clarity, safety of use, and ease of operation. Meanwhile, design validation aimed to assess the design and layout, function and operation.

With this media, the process of understanding the procedures for installing kWh meters can be done more quickly and systematically, thus facilitating implementation during laboratory practice and in working conditions in the field. In this study, the design used follows research procedures. According to research from Gogahu D, (2020), by

applying this 4D development model, it consists of 4 stages, namely: define, design, development and disseminate which have been adjusted and modified as can be seen in the following figure. define, design, develop, and disseminate, which have been adjusted and modified as seen in the following figure 1.

The research process for designing a kWh meter trainer begins with the initial stage or needs identification, where researchers observe problems in the learning process, particularly the limited practical media that can explain the working concept of a kWh meter in a realistic manner. Next, a needs analysis is conducted to determine the specifications, components, and features required for the trainer to support practical learning in electrical installation engineering.

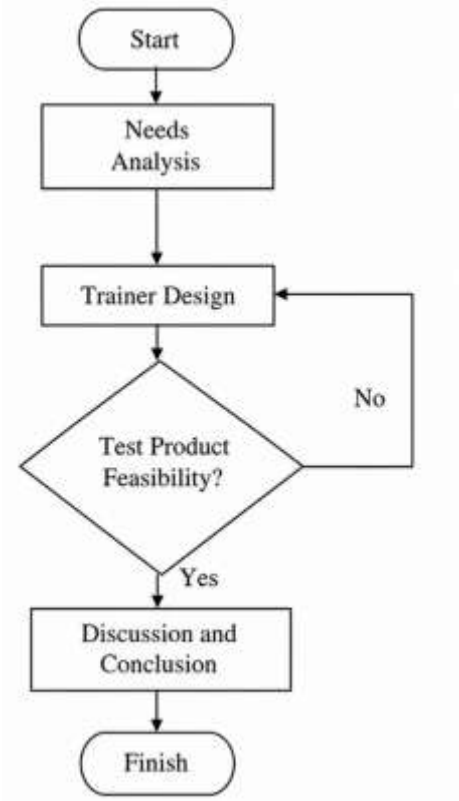


Figure 1. Kwh Meter Trainer Research Flow

The research instrument was a validation sheet with a Likert scale (1-5). Data was analyzed descriptively and quantitatively to determine the product feasibility category. The following equation will show the formula for calculating the trainer's feasibility percentage in the following formula. The expert validation result categories are determined based on the response levels shown in Table 1 below.

Table 1. Expert Validation Result Categories

Categories	Percentage Rate (%)
Highly Worth It	80 – 100
Worthy	61 – 80
Quite Decent	41 – 60
Not Eligible	21 – 40
Very Unworthy	0 - 20

The analysis was conducted by calculating the average score and interpreting the results based on the assessment criteria. In this study, researchers collected expert validation data by presenting the kWh meter trainer or teaching aid to media experts and process design experts, accompanied by the distribution of media validation sheets and design validation sheets. The results of the tests that had been carried out were then discussed to see the advantages, disadvantages, and opportunities for future trainer development. In the final section, this study closed with a conclusion that summarized the success of the kWh meter trainer design as an innovative and effective learning medium in Electrical Installation practice. The kWh meter trainer experiment scheme can be seen in Figure 2 below.

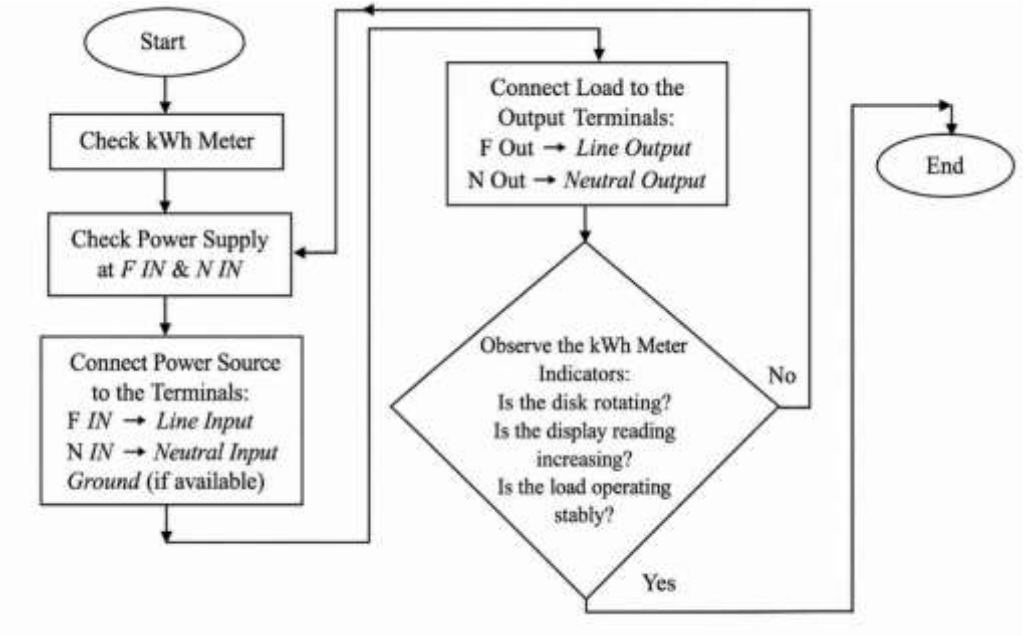


Figure 2. Kwh Meter Trainer Experiment Scheme

Results and Discussion

The resulting research product is a kWh Meter trainer. The trainer design is made in the form of a medium-sized panel board so that it is easy to move and use, this kWh meter trainer is also equipped with a wiring diagram that is arranged clearly and easily understood, On the front there is a display that functions to show the amount of electrical energy that has been used. Inside the kWh meter there is a disk or aluminum plate that will rotate when electric current flows, where the rotation speed adjusts to the amount of power used, the display on the kWh meter functions as an indicator of the amount of electrical energy that has been used, the numbers displayed indicate the amount of energy consumption in kilowatt hours (kWh). At the bottom of the kWh meter there is a cable terminal consisting of phase and neutral cables. The phase cable functions as an entry and exit path for electric current from the source to the black cable installation, while the neutral cable functions as a return conductor for the blue cable electric current, and also grounding as a safety measure in the event of an overcurrent of the yellow cable. Through the diagram, this trainer can be seen directly the wiring flow, from the power source to the load. The image of the kWh Meter trainer wiring diagram is in Figure 3 below.

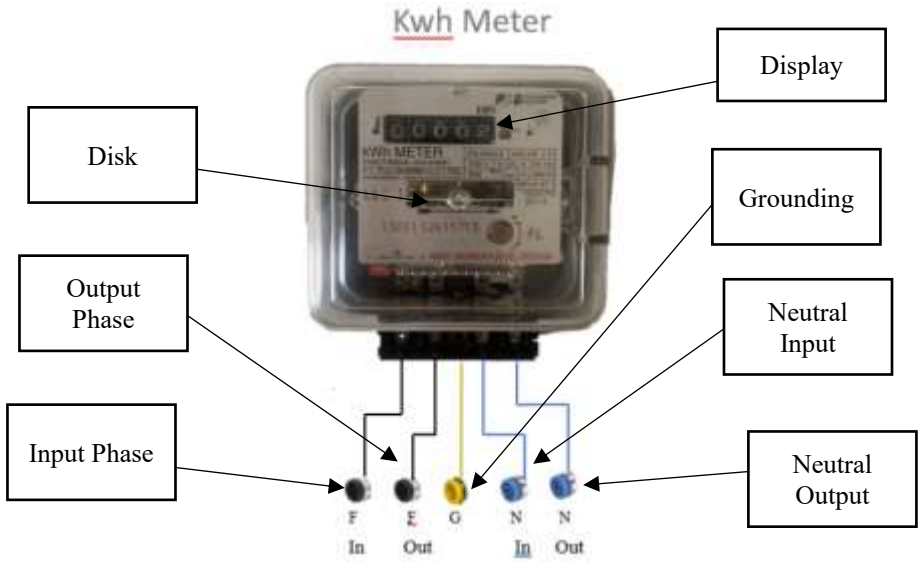


Figure 3. *Wiring* Diagram *Trainer* kWh Meter

In the kWh meter trainer, shown in Figure 3, the electrical current from the source first enters through the F IN terminal as the phase and the N IN terminal as the neutral. These two paths then enter the kWh meter trainer, where the device begins to calculate how much electrical energy is used. Meanwhile, the yellow G terminal serves as a ground or safety path, so it does not affect the energy measurement process, but is important for safety. After the electricity passes through the measurement process, the current will exit through the F OUT and N OUT terminals and then be distributed to loads such as lights or other equipment. With this flow, the trainer helps users understand how electricity flows from the source, enters the kWh meter, and is then forwarded to the load, while also showing how the kWh meter trainer records energy usage in a real and easy-to-understand manner.

Testing of this kWh meter trainer involved two media expert validators, two design expert validators who assessed how this tool works and how easy this tool is to use in the learning process. They looked at the appearance of the tool, the neatness of the wiring, the security of the circuit, and the clarity of the function of each terminal. From the assessment results, both validators stated that this trainer was suitable for use as a learning medium. They only provided a few small suggestions, such as clarifying the terminal labels and adding instructions for use so that it would be quicker to understand how the tool works.

In addition, four lecturers from the Electrical Engineering Education Study Program at UIN Ar-Raniry Banda Aceh also provided an assessment. The lecturers reviewed the tool's suitability for classroom and laboratory learning needs. They assessed its measurement function, workflow, and the material's suitability to the required competencies. The lecturers agreed that the kWh meter trainer was highly beneficial, as it helped them understand electrical energy flow, how it works, and proper wiring techniques.

They assessed this tool as a representative tool for practical use in educational settings. The results of this assessment served as the basis for determining whether the kWh Meter Trainer met the eligibility standards for use as a learning tool. The media validation results can be seen in the following table.

Table 2. Expert Design Validation Results

No	Statement Criteria	Criteria	
		Validator 1	Validator 2
	Physical Design & Layout		
1.	The layout of the components is neatly arranged and easy to understand	5	5
2.	Quality of trainer construction	5	4
3.	Safety of using electrical components	5	3
4.	Secure wiring, not cluttered	5	4
5.	Standardization of symbols and wiring diagrams	5	4
6.	Quality of physical materials (panels, wiring, sockets, boxes)	5	4
	Functions & Operations		
7.	Electric Wiring according to safety standards	5	4
8.	Implementing occupational safety and health (K3) on kWh meter trainers	5	4
9.	Properly label the input–output wiring of the kWh meter	5	5
	Benefits		
10.	Students can expand their understanding of kWh meters	4	5
12.	Can be used for Project Based Learning (PjBL)	5	5
13.	These trainers can encourage active and collaborative learning	4	5
14.	Provides Exercise safe conditions before working with real electrical installations	5	5
Quantity		62	57
Introduce yourself		88	81
Overall percentage		**84**	

Expert Design Validation Analysis Referring to Table 2 above, the feasibility category can be seen from the evaluation results conducted by media experts. Based on the assessment results by two validators, the evaluation of the kWh meter trainer covers several aspects such as physical design and layout, function and operation, and benefits. In terms of physical design and layout, the trainer received a very good rating, especially related to the arrangement of components which was considered neat and easy to understand. The quality of construction, cable arrangement, standardization of symbols and wiring diagrams, and the quality of the physical material also received positive

assessments. However, on the safety indicator related to the use of electrical components, the second validator gave a lower score, indicating the need for improvements in the safety area so that the trainer can be used more optimally. Validation was carried out by lecturers in the Electrical Installation Engineering course, S1 Electrical Engineering Education, Faculty of Tarbiyah and Teacher Training, Uin Ar-Raniry University, Banda Aceh. The results of the validation test by media experts can be seen in Table 3 below.

Table 3. Media Expert Validation Results

No	Statement Criteria	Criteria	
		Validator 1	Validator 2
	Media Form		
1.	The components on the props can be shown	5	5
2.	These props are easy to use and understand	4	4
3.	This teaching aid has the main component, namely the kWh meter	5	5
4.	This electrical installation teaching tool can be a medium in carrying out practicum	5	5
5.	The displayed props can present the concept in the installation of Electrical	5	5
	General Appearance		
6.	The design of these props can attract attention	5	5
7.	The precise layout of the components on the props so that it can be an attraction	4	5
8.	The display of this teaching tool is simple so that it can understand the work of the kWh meter	5	5
	Practical		
10.	The tools and materials used in this praga tool are easy to get	4	5
11.	These props are relatively affordable in the initial cost	4	4
12.	Tools and materials used in simple props	5	5
13.	The tools and materials used are easy to understand their functions	5	4
14.	These props have long-term durability	4	5
15.	The tools and materials on the props are suitable for use	5	5
	Technical		
16.	The praga kWh meter is working properly	5	5
17.	The operation of this praga tool has an easy-to-understand way of working	4	4
18.	The operation of this praga tool is carried out manually	5	5

No	Statement Criteria	Criteria	
		Validator 1	Validator 2
	Media Quality		
19.	This praga tool has a high marketability	4	5
20.	Lower maintenance costs	5	5
Quantity		88	91
Introduce yourself		88	91
Overall percentage		**89**	

Based on the assessment results from the two validators in tables 2 and 3 above, the kWh meter trainer demonstrated excellent results in terms of media format and general appearance. The components of the trainer are clearly visible, easy to use, and easy to understand. The presence of the kWh meter trainer as the main component is considered appropriate for the learning objectives. Furthermore, this training tool is able to function well as a practical medium in electrical installation courses because it can help explain electrical installation concepts in a realistic manner.

In terms of appearance, the design of the teaching aid is considered attractive, the arrangement of the components is neat, and its simple appearance makes it easy to understand how the kWh meter trainer works. In terms of practicality, this teaching aid uses tools and materials that are relatively easy to find and have a fairly affordable manufacturing cost. The teaching aid is also considered strong and durable enough for long-term use, making it suitable for use in practical activities. Although there are slight differences of opinion between validators regarding the ease of understanding the function of some tools and materials, overall the practicality aspect of the kWh meter trainer teaching aid remains in the good to very good category.

From the validation result, which assessed for both design and media, received very positive feedback from both validators. For the design section, the media validator scored 89%, while the design validator scored 84%. This indicates that the design was generally deemed very suitable, but the design validator still found some minor areas of improvement to be quite low. Meanwhile, the media assessment scored even higher than the design assessment, still giving 84%, and the media validator with the highest score of 89%, indicating the developed media was deemed very good and ready for use. Overall, all scores were above 80%, concluding that the product is highly suitable for use, with the strongest assessment being the quality of the media.

Essentially, this study uses a kWh meter trainer as a learning tool for practical work in Electrical Installation Engineering courses. The device is designed as a medium-sized board for easy portability and operation. The simple yet functional design aims to integrate theoretical knowledge and practical electrical work practices. The trainer was tested through validation by design and media experts, with assessment criteria covering physical design, safety, operational functionality, and learning benefits. The validation results showed that the trainer met the eligibility standards for a learning tool, with all percentage

scores above the 80% threshold. This demonstrates that, in terms of design and operation, the kWh meter trainer is academically and technically sound for use in practical learning.

Assessments by two expert design validators indicated that the component layout, construction quality, and wiring were deemed satisfactory and safe for use, although several improvements were suggested, such as sharpening the terminal labels and user manuals. Furthermore, assessments by the program lecturers indicated that the kWh meter trainer was very helpful in explaining the concept of electrical energy flow, wiring techniques, and the working principles of electrical measuring instruments. The lecturers assessed that this media was in accordance with the competencies required to be mastered.

Overall, the validation results indicate that this kWh meter trainer is not only feasible in terms of design and media, but also relevant in the context of learning electrical installation techniques. The high validation score and support from media and design experts provide a strong basis for this product's suitability for use in practical activities and has significant potential to provide a more structured, safe, and contextual learning experience for students.

Conclusion

Based on research and development with a 4D model, the kWh meter trainer created has met the learning needs of Electrical Installation Engineering in the Electrical Engineering Education Department of UIN Ar-Raniry Banda Aceh. The validation results show a very feasible category, with a design value of 84% and media 89%, which indicates that the trainer has a good design, is safe, practical, easy to use, and supports learning. Overall, this trainer is suitable for use as a learning medium to improve understanding and skills and overcome the limitations of practical media in the laboratory.

References

[1] N. S. N. Saadah, R. Anggraeni, and D. A. Fitriani, “Menakar relevansi metode pembelajaran konvensional pada pendidikan Islam di era digital,” Jurnal Pendidikan Indonesia: Teori, Penelitian, dan Inovasi, vol. 5, no. 4, pp. 137–150, 2025, doi: 10.59818/jpi.v5i4.1667.

[2] A. Rahman BP, S. A. Munandar, A. Fitriani, Y. Karlina, and Y. Yumriani, “Pengertian pendidikan, ilmu pendidikan dan unsur-unsur pendidikan,” Al-Urwatul Wutsqa: Kajian Pendidikan Islam, vol. 2, no. 1, pp. 1–8, Jun. 2022

[3] A. Daniyati, I. B. Saputri, R. Wijaya, S. A. Septiyani, and U. Setiawan, “Konsep dasar media pembelajaran,” Journal of Student Research, vol. 1, no. 1, pp. 282–294, 2023, doi: 10.55606/jsr.v1i1.993.

[4] S. Rachman, Khairunnisa, and Y. Rizal, “Pelatihan protokol Modbus kWh meter digital,” Jurnal IMPACT: Implementation and Action, vol. 7, no. 1, pp. 21–27, 2024, doi: 10.31961/impact.v7i1.14442

[5] R. Ekawati, E. Permata, M. Fatkhurrohman, I. Irwanto, and S. Afridah, “Pengembangan media pembelajaran trainer kit teknik digital berbasis cooperative learning approach,” Lectura: Jurnal Pendidikan, vol. 12, no. 2, pp. 180–193, 2021, doi: 10.31849/lectura.v12i2.7486.

[6] V. Ventriolla, Purwantono, Mulianti, and E. Indrawan, “Rancang bangun trainer elektromagnetik sebagai media pembelajaran sistem kelistrikan dan mesin industri untuk siswa kejuruan teknik pemesinan di SMK Negeri 1 Sumatera Barat,” Vomek, vol. 5, no. 1, pp. 65–70, Feb. 2023, doi: 10.24036/vomek.v5i1.503.

[7] D. V. Nuralda, "Analisa penggantian kWh meter bermasalah terhadap efektifitas kWh jual," Jurnal Informatika dan Teknik Elektro Terapan, vol. 12, no. 1, pp. 148–154, 2024, doi: 10.23960/jitet.v12i1.3951

[8] A. Abadi, R. Widya, and J. Julsam, "Rancang bangun pemutus tegangan pada kWh meter pelanggan PLN," Jurnal Andalas: Rekayasa dan Penerapan Teknologi, vol. 1, no. 1, pp. 37–46, Jun. 2021, doi: 10.25077/jarpet.v1i1.2

[9] Suparmono, T. Sitepu, N. Sitorus, S. Pardede, Cholish, and I. Nofri, "Design a realtime datalogger on a simple house KWH meter with a capacity of 1300 VA," International Journal of Research and Review, vol. 10, no. 12, pp. 352–359, Dec. 2023, doi: 10.52403/ijrr.20231238

[10] A. Yani, "Pengaruh harmonisa terhadap kesalahan pengukuran energi listrik pada kWh meter analog/digital," Buletin Utama Teknik, vol. 14, no. 2, pp. 99–105, Jan. 2019. [Online]. Available: https://jurnal.uisu.ac.id/index.php/but/article/view/1092

[11] T. Taryana, C. Kuntadi, Y. Suprihartini, and R. Sadiatmi, "Faktor-faktor yang mempengaruhi keandalan instalasi listrik," Jurnal Manajemen Pendidikan dan Ilmu Sosial, vol. 4, no. 1, pp. 531–537, 2023, doi: 10.38035/jmpis.v4i1.1457.

[12] Y. Ridal, "Studi analisis susut energi listrik non teknis dengan cara optimalisasi peremajaan kWh meter pascabayar 1 phasa di PT. PLN (Persero) ULP Painan," Jurnal Teknik Industri Terintegrasi, vol. 6, no. 1, pp. 354–361, Apr. 2023, doi: 10.31004/jutin.v6i1.18022.

[13] D. Gunawan, D. Erwanto, and Y. Shalahuddin, "Studi komparasi kWh meter pascabayar dengan kWh meter prabayar tentang akurasi pengukuran terhadap tarif listrik yang bervariasi," Setrum: Sistem Kendali-Tenaga-Elektronika-Telekomunikasi-Komputer, vol. 7, no. 1, pp. 158–168, Jun. 2018, doi: 10.36055/setrum.v7i1.3408.

[14] R. A. Widyastri and V. U. Hasibuan, "Penguasaan lembar kerja siswa (LKS) IPA materi daur ulang air menggunakan model contextual teaching and learning untuk meningkatkan hasil belajar siswa kelas V SDIT Al-Khair Kabupaten Deli Serdang T.A. 2019/2020," REKOGNISI: Jurnal Pendidikan dan Kependidikan, vol. 5, no. 1, pp. 39–49, Jun. 2020. [Online]. Available: https://jurnal.unusu.ac.id/index.php/rekognisi/article/view/131

[15] A. Rahayu, "Metode penelitian dan pengembangan (R&D): Pengertian, jenis dan tahapan," DIAJAR: Jurnal Pendidikan dan Pembelajaran, vol. 4, no. 3, pp. 459–470, Jul. 2025, doi: 10.54259/diajar.v4i3.5092.

[16] A. R. Sari, H. A. Husnawati, J. Suryono, M. Marzuki, and A. Mulyapradana, Metode Penelitian Kualitatif, Kuantitatif, dan R&D. Bekasi, Indonesia: Yayasan Putra Adi Dharma, 2025, ISBN: 978-634-7261083.

[17] A. Hudaya Salsabila, T. Iriani, and S. Sri Handoyo, "Penerapan Model 4D Dalam Pengembangan Video Pembelajaran Pada Keterampilan Mengelola Kelas."

[18] M. S. Dwi Putra and S. Abadi, "Penjadwalan Ekonomis Pada Pembangkit Termal Dengan Menggunakan Particle Swarm Optimization," *Jurnal Teknik Mesin Sinergi*, vol. 21, no. 1, pp. 156–162, Apr. 2023, doi: 10.31963/sinergi.v21i1.4239.

[19] A. H. Salsabila, T. Iriani, and S. S. Handoyo, "Penerapan model 4D dalam pengembangan video pembelajaran pada keterampilan mengelola kelas," Jurnal Pendidikan West Science, vol. 1, no. 8, pp. 495–505, Aug. 2023, doi: 10.58812/jpdws.v1i08.553.

[20] D. G. S. Gogahu and T. Prasetyo, "Pengembangan media pembelajaran berbasis e-bookstory untuk meningkatkan literasi membaca siswa sekolah dasar," Jurnal Basicedu, vol. 4, no. 4, pp. 1004–1015, Aug. 2020, doi: 10.31004/basicedu.v4i4.493.

[21] A. K. Podder, S. Islam, and A. U. Rahman, "A multivibrator and oscillator trainer kit for an emerging pedagogy in engineering," International Journal of Electrical Engineering Education, vol. 60, no. 4, pp. 367–382, Oct. 2023, doi: 10.1177/0020720920980972.

[22] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," Journal of Engineering Education, vol. 94, no. 1, pp. 121–130, Jan. 2005, doi: 10.1002/j.2168-9830.2005.tb00833.x.

[23] J. Ma and J. V. Nickerson, "Hands-on, simulated, and remote laboratories: A comparative literature review," ACM Computing Surveys, vol. 38, no. 3, Art. no. 7, Sep. 2006, doi: 10.1145/1132960.1132961

[24] T. de Jong, M. C. Linn, and Z. C. Zacharia, "Physical and virtual laboratories in science and engineering education," Science, vol. 340, no. 6130, pp. 305–308, Apr. 2013, doi: 10.1126/science.1230579

[25] J. R. Brinson, "Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research," Computers & Education, vol. 87, pp. 218–237, Sep. 2015, doi: 10.1016/j.compedu.2015.07.003.

[26] V. Potkonjak et al., "Virtual laboratories for education in science, technology, and engineering: A review," Computers & Education, vol. 95, pp. 309–327, Apr. 2016, doi: 10.1016/j.compedu.2016.02.002.

[27] P. Guo, N. Saab, L. S. Post, and W. Admiraal, "A review of project-based learning in higher education: Student outcomes and measures," International Journal of Educational Research, vol. 102, Art. no. 101586, 2020, doi: 10.1016/j.ijer.2020.101586.

[28] J. Chen, A. Kolmos, and X. Du, "Forms of implementation and challenges of PBL in engineering education: A review of literature," European Journal of Engineering Education, vol. 46, no. 1, pp. 90–115, 2021, doi: 10.1080/03043797.2020.1718615

[29] C. Viegas et al., "Impact of a remote lab on teaching practices and student learning," Computers & Education, vol. 126, pp. 201–216, Nov. 2018, doi: 10.1016/j.compedu.2018.07.012.

[30] A. van den Beemt, S. Groothuijsen, L. Özkan, and W. Hendrix, "Remote labs in higher engineering education: Engaging students with active learning pedagogy," Journal of Computing in Higher Education, vol. 35, no. 2, pp. 320–340, 2023, doi: 10.1007/s12528-022-09331-4