

Development of a Pico-Hydro Trainer for Renewable Energy Practicum in Universities

Arwadi Sinuraya¹, Denny Haryanto Sinaga^{1,4*}, Lastama Sinaga², Reza Arbi Azizi Lubis³, Dito Yudhistira Nugroho¹, Ricky Nelson Tampubolon³

¹Study Program of Electrical Engineering, Faculty of Engineering, Universitas Negeri Medan, Medan, Indonesia.

²Study Program of Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Medan, Indonesia.

³Study Program of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Medan, Medan, Indonesia.

⁴Innovation Centre of Renewable Sources and Waste Integration for Sustainable Energy (PUI-PT INNERWISE), Universitas Negeri Medan, Medan, Indonesia.

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Corresponding Author:

Denny Haryanto Sinaga

denny.sinaga@unimed.ac.id

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Abstract: This study aimed to develop a Pico Hydro trainer as a practical learning tool to support renewable energy education in higher education. The development followed the ADDIE model, consisting of analysis, design, development, implementation, and evaluation phases. The trainer was constructed using essential components, including a turbine, AC generator, high-pressure pump, digital monitoring instruments, and safety features. Expert validation results indicated a feasibility score of 3.60 from the material expert, 3.50 from the media expert, and 3.56 from user responses, with an average rating of 3.55 that was categorized as “very feasible.” Performance testing demonstrated the trainer’s ability to generate up to 22V at 576 RPM under no-load conditions. Additionally, student learning outcomes improved significantly, as shown by a normalized gain score of 0.714. These findings suggest that the Pico Hydro trainer is effective in integrating theoretical knowledge with hands-on experience, and it offers a safe, portable, and efficient solution for laboratory-based instruction in renewable energy systems.

Keywords: Learning effectiveness; Pico hydro; Renewable energy; Technical education; Trainer development

Introduction

Energy is a crucial need for human life, with electrical energy being one of the most important forms that support daily activities and technological development (Bandri et al., 2021). As global energy demand continues to rise, the utilization of local energy potential becomes increasingly vital to support national energy independence. Indonesia, as a country rich in natural resources, particularly water, has significant potential to develop hydro-based electricity generation systems (Hantarum et al., 2016). This potential must be optimized, especially through the utilization of small-scale systems such as Pico Hydro, a renewable energy technology with a capacity of less than 5 kW (Ibrahim et al., 2023; Wardhany et al., 2025; Hidayat & Choifin, 2025). We can see the working principle of this Pico

Hydro generator in Figure 1. Pico Hydro operates by channeling water from a certain height to a lower point, where the gravitational force (head) is converted into mechanical energy to drive a turbine and generator, thereby producing electricity (Hantarum et al., 2016).

The utilization of renewable energy, such as Pico Hydro, aligns with the national strategy of diversifying primary energy sources, especially due to the limited availability of non-renewable energy (Bandri et al., 2021). Moreover, hydroelectric power plant development across multiple scales receives comprehensive legislative support through Law Number 20 of 2002 concerning Electricity. This legislation explicitly mandates that “to guarantee the availability of primary energy for electrical power generation, the utilization of local energy sources is prioritized, with the obligation to prioritize renewable

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energy source utilization.” The national energy policy trajectory is subsequently strengthened by Presidential Regulation Number 5 of 2006, which establishes a quantitative target of 17% renewable energy contribution to the primary energy mix by 2025. This regulatory architecture emphasizes the strategic imperative of renewable energy integration within the national electrical infrastructure, establishing a conducive policy environment for sustainable energy transition and distributed generation system deployment (Sinaga et al., 2021).

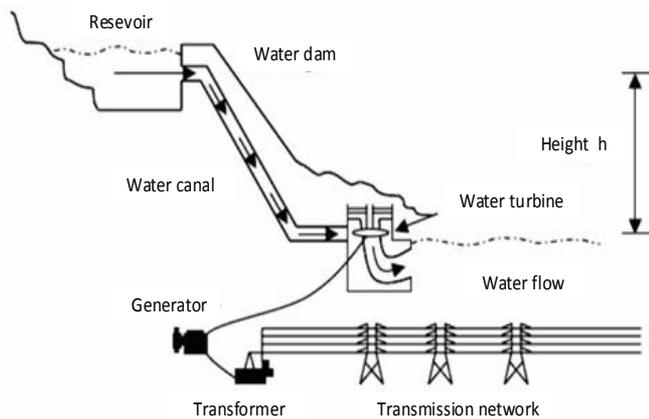


Figure 1. Picohydro principle

To support the implementation of such national energy policies, educational institutions, especially at higher education level, play a crucial role in preparing future professionals who are capable of designing and applying renewable energy systems (Rachmat & Tampubolon, 2013). In line with the global shift toward sustainable energy, higher education institutions are therefore required to update their curricula to prepare students for future challenges. However, the limited availability of practical and applicable training media remains a major obstacle in the learning process of renewable energy in many educational institutions. This highlights the importance of developing a Pico Hydro trainer that can be used as a laboratory tool in engineering education (Azis & Fitri, 2020). Such media enables students to understand the basic principles of energy conversion, system efficiency, and technical characteristics of hydropower systems through a hands-on, learning-by-doing approach (Morales et al., 2023).

In this context, several studies have demonstrated the effectiveness of Pico Hydro trainers as educational tools in engineering. Morales et al. (2023) noted that the design of a pico-hydraulic training system significantly enhances students’ understanding of power generation and measurement systems, especially when integrated with Internet of Things (IoT) technology and QFD-TRIZ-based design methodologies, which allow for real-time data monitoring and flexible system operation. This

aligns well with the demands of Industry 4.0 and Education 4.0.

On the other hand, a case study conducted by Ibrahim et al. (2023) in Dusun Sinar Negeri showed that a Pico Hydro system was able to generate 8.79 watts of power from a water flow with a head of 0.75 meters and a discharge of 0.002 m³/s. This demonstrates that Pico Hydro-based learning tools can not only be effective in education but also serve as real-world solutions for electricity needs in remote areas. It strengthens the link and match between theoretical knowledge and practical applications.

This study aims to design and implement a laboratory-based Pico Hydro trainer to support renewable energy practicum activities in higher education institutions. The focus includes the system’s technical design, component integration, performance evaluation, and user feedback from both students and lecturers. The expected outcome is to improve the effectiveness of the learning process while also paving the way for the development of contextual, cost-effective, and sustainable teaching tools.

Method

This study adopts a Research and Development (R&D) approach, which aims to produce new products or improve existing ones and evaluate their effectiveness. According to Sugiyono (2017), R&D is a systematic method used to develop and validate educational products that can be scientifically justified. Saputro (2017) emphasizes that R&D serves to address real-world needs, particularly in developing relevant and applicable instructional media. Winaryati et al. (2021) describe R&D as a process that stems from existing problems requiring product-based solutions, whether through the enhancement of current tools or the creation of innovative solutions. Furthermore, Ibrahim et al. (2018) view development research as a means to evaluate and improve upon previous studies or prototypes, ensuring the continuity of improvements based on user needs.

The development of the Pico Hydro trainer followed the ADDIE model, which includes five phases: Analysis, Design, Development, Implementation, and Evaluation. Figure 2 illustrates the conceptual flow of the ADDIE model used in this study.

This model was selected due to its structured and iterative process suitable for educational product development (Lee & Owens, 2004). In the analysis phase, the study identified instructional goals, learner characteristics, and the contextual needs for integrating a pico hydro trainer into laboratory activities. The design phase involves formulating instructional objectives,

designing the trainer system, defining performance indicators, and planning evaluation tools. During the development phase, the actual construction of the trainer takes place, including the assembly of components such as turbines, piping, generators, and digital monitoring systems (Nababan et al., 2012). The implementation phase consists of pilot-testing the prototype with students and instructors to evaluate usability and functional effectiveness (Alatas et al., 2025). Finally, in the evaluation phase, both formative and summative evaluations are conducted to assess the trainer’s quality and overall educational impact.

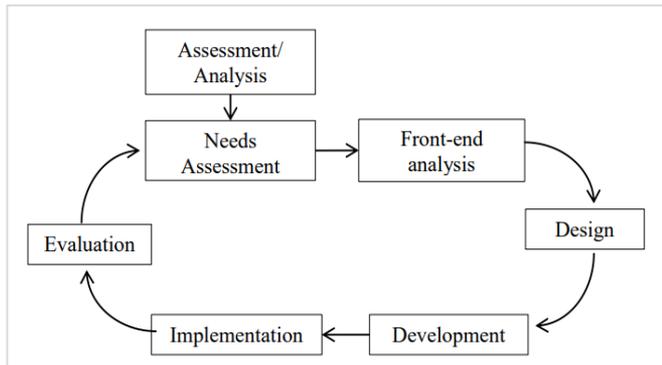


Figure 2. ADDIE development model cycle

The feasibility assessment of the Pico Hydro trainer questionnaire was distributed to experts to evaluate the feasibility of the Pico Hydro trainer and its supporting learning module. The assessment focused on four aspects: material relevance, clarity of information, media design, and ease of use.

To assess the feasibility of the Pico Hydro trainer, an expert validation questionnaire was used. The instrument adopted a Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree), covering aspects such as content relevance, instructional clarity, design quality, and ease of use. The scoring criteria are shown in Table 1.

Table 1. Assessment Criteria Table (Rohman, 2017)

Assessment Criteria	Assessment Score
Totally Agree	4
Agree	3
Disagree	2
Strongly Disagree	1

The highest value is 4 and the lowest is 1, with a total of 4 categories. The interval distance obtained from the calculation is 0.75 based on the calculation using the following formula (1):

$$Interval = \frac{Highest\ score - Lowest\ score}{Number\ of\ categories} \tag{1}$$

To categorize the results of expert and user evaluations, score intervals were used to define levels of feasibility. Table 2 presents the classification criteria for interpreting average scores, from "totally unfeasible" to "very feasible."

Table 2. Eligibility Table (Rohman, 2017)

Average Score	Category
>3.25 - 4.00	Very Feasible
>2.50 - 3.25	Feasible
>1.75 - 2.50	Not Feasible
1.00 - 1.75	Totally Unfeasible

To calculate the average score for each item, we can see (2) where the value is calculated using the formula where: \bar{X} is the mean score, $\sum x$ is the total score, and n is the number of items (Rohman, 2017).

$$\bar{X} = \frac{\sum x}{n} \tag{2}$$

The Normalized Gain (N-Gain) is used to measure the improvement in students’ cognitive learning outcomes after treatment, based on their pre-test and post-test scores. It is calculated as (3):

$$N - Gain (g) = \frac{mean\ posttest - mean\ pretest}{Max\ score - mean\ pretest} \tag{3}$$

To evaluate the cognitive effectiveness of the learning intervention, a Normalized Gain (N-Gain) was calculated based on students’ scores, and the categories used to interpret N-Gain values are outlined in Table 3.

Table 3. Effectiveness Table (Supriadi, 2021)

Percentage Value	Category
<40	Not Effective
40 - 55	Less Effective
56 - 75	Moderately Effective
>76	Effective

Result and Discussion

In the analysis phase, researchers identified the instructional needs based on the learning content of energy conversion systems, particularly within vocational and technical education. The current laboratory facilities were found to be limited, providing only trainers for solar power, wind power, and generator-motor systems, with no dedicated trainer available for pico-hydro power generation (Rahmawati et al., 2023; Hetharia et al., 2021; Hetharia et al., 2021; Arsa et al., 2024; Sitorus et al., 2024). This lack of practical tools is concerning, as the curriculum explicitly requires students to understand and explore various forms of renewable energy—including pico-hydro—not only

through theoretical learning but also via hands-on experience (Connolly et al., 2010).

To address this gap, the researchers referred to the functional structure of a typical pico-hydro system, as illustrated in Figure 3. The diagram outlines a sequential process starting from a water source, followed by a hydraulic pump to increase water pressure, a water turbine to convert hydraulic energy into mechanical energy, and a turbine shaft (peros turbin) linked to a generator for electrical production (Dwilesmana & Cahyono, 2023; Bozorgi et al., 2013). The resulting electricity then flows through a distribution panel and is monitored by measuring instruments such as voltmeters, ammeters, and frequency meters before being connected to electrical loads.

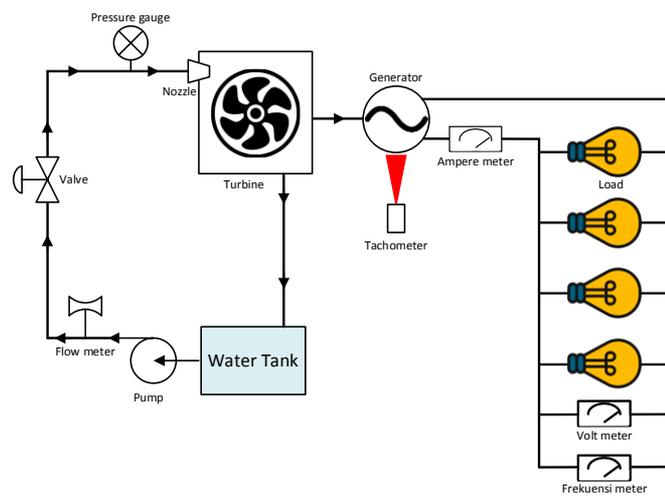


Figure 3. Picohydro trainer system

The systematic flow in Figure 4 highlights the essential components and instrumentation required for effective learning. Consequently, the analysis supports the development of a portable and corrosion-resistant pico-hydro trainer that accurately simulates each stage of the conversion process – from mechanical to electrical energy – while incorporating visual indicators, interactive wiring systems, and real-time monitoring tools. Such a trainer would enable students to directly observe, interact with, and understand the practical applications of energy conversion in renewable systems.

The design phase focused on translating the results of the analysis into structured instructional planning. Researchers formulated clear learning objectives aligned with renewable energy competencies and outlined the system design for the pico-hydro trainer (Tejedor et al., 2019). This included determining necessary components such as turbines, generators, piping systems, and sensors, as well as defining performance indicators and developing instruments. The physical structure of the trainer was drafted to ensure portability, safety, and ease

of use in laboratory settings. Figure 5 shows the detailed frame design along with dimensions for construction.

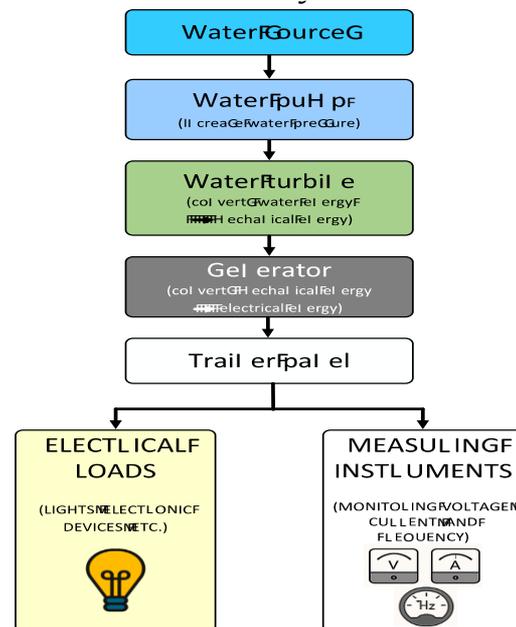


Figure 4. Picohydro trainer work system flow

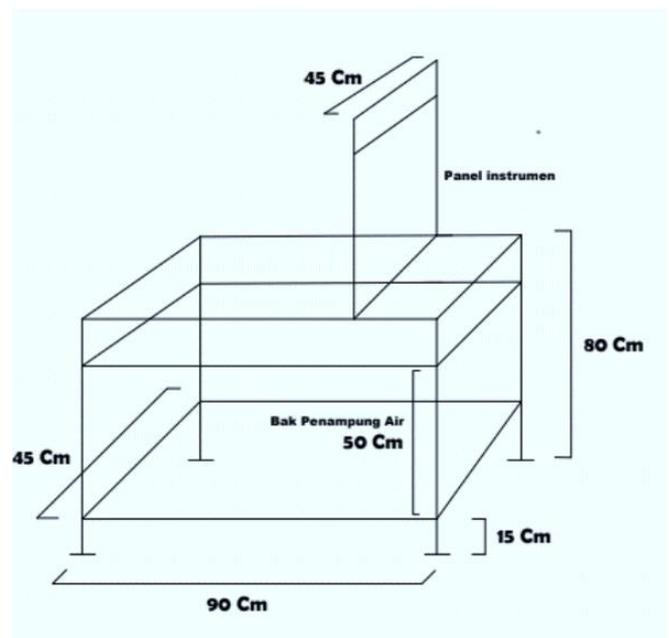


Figure 5. Picohydro frame design and dimensions

The internal layout was carefully arranged to represent the complete energy conversion cycle, including water flow, turbine movement, generator output, and measurement instrumentation. The proposed layout is shown in Figure 6.

During the development phase, the pico-hydro trainer prototype was physically constructed based on the system design (Ferdiansyah, 2023; Adiguna & Widagdo, 2023; Perdana & Saputra, 2023). The process

involved assembling mechanical and electrical components including the water turbine, PVC piping, AC generator, load system, and digital displays for voltage and current (Quipo & Quipo, 2025). The development also included integrating measurement sensors and a user-friendly interface to support monitoring and learning. After the construction phase, a functional prototype of the Pico Hydro trainer was developed. Figure 7 displays the completed prototype, including its structural frame, integrated components, and control interface.

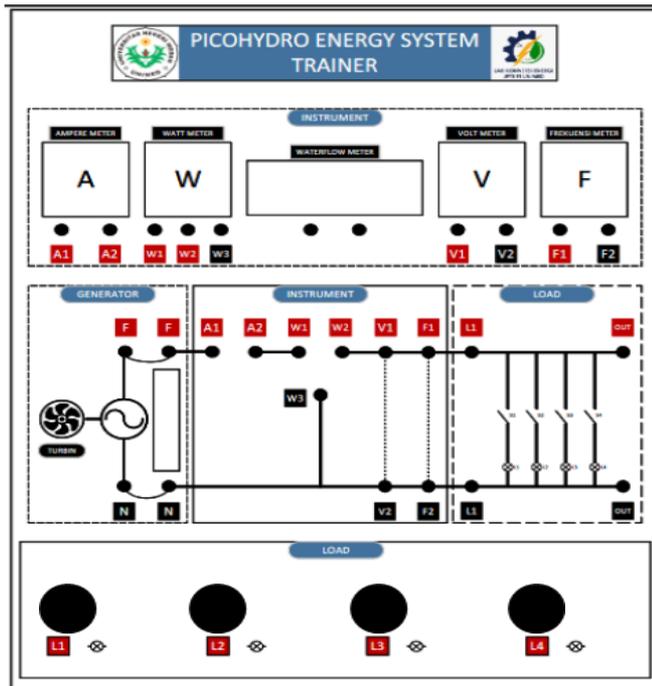


Figure 6. Component layout model design



Figure 7. Trainer Picohydro

Figure 8. provides a side view of the trainer, clearly showing the mechanical components and fluid path. The transparent acrylic tanks enable real-time observation of water flow, turbine rotation, and generator coupling, offering students a visual understanding of the energy conversion process from mechanical to electrical power (Subekti et al., 2021).



Figure 8. Trainer from side view

The implementation phase consisted of pilot testing the trainer with a group of students and instructors in a controlled laboratory setting (Sani & Jannah, 2020; Naufal & Irwanto, 2023). This stage was aimed at evaluating the usability, functionality, and clarity of the trainer's operation. Students performed learning tasks using the trainer while instructors observed and provided feedback. Data were collected through pre-test and post-test instruments, as well as questionnaires and interviews, to assess initial learning outcomes and user responses.

In the final evaluation phase, both formative and summative assessments were carried out to determine the trainer's educational effectiveness. Formative evaluation was conducted during development through expert validation, while summative evaluation involved analyzing pre-test and post-test results using normalized gain (N-Gain) and student feedback. The results indicated a positive improvement in students' understanding of renewable energy systems, with the pico-hydro trainer proving to be effective, practical, and appropriate for use in technical education.

A functional test was conducted to ensure that each component of the trainer performed as expected under laboratory conditions. The test covered electrical and

mechanical parts, as well as protection systems. The detailed results are presented in Table 4.

Table 4. Component Test Table

Components Being Tested	Test Results
Generator	18-22 Volt
Pump	120 Bar
Turbine	443-576 RPM
Lamp	Work according to function
Instrument	Work according to function
Protection (MCB)	Work according to function

The results of the functional test on the laboratory-scale Pico Hydro trainer showed that this device can produce a maximum voltage of 22V at 576 RPM under no-load conditions. This result is consistent with findings by Sinuraya et al. (2024) and Durrani et al. (2019), who reported that a similar laboratory-scale Pico Hydro trainer reached 22V at 576 RPM under no-load conditions, validating the reliability of such systems in controlled educational environments. The system worked stably under various test conditions, although there was a decrease in output voltage that was proportional to the decrease in water pressure. This emphasizes the importance of maintaining stable water flow to ensure optimal output performance.

A comprehensive analysis was conducted on the performance and advantages of the developed Pico Hydro trainer. The evaluation results revealed that the trainer possesses several key features that enhance its effectiveness as a renewable energy learning tool. One of its strengths lies in its adjustable water flow speed, which is complemented by a digital display that allows for real-time monitoring and control of system parameters. The system also includes a water pressure measurement feature supported by a 120-bar high-pressure pump, simulating realistic operational conditions.

From the electrical measurement perspective, the trainer is equipped with complete instrumentation, including an ammeter, voltmeter, wattmeter, and frequency meter (Aswad Alfian et al., 2023). It features built-in lamp loads that can be varied, along with banana jack connectors that allow the addition of external loads, providing flexibility for different experimental scenarios. This enables students to explore a variety of setups and calculate power efficiency under different load conditions.

The core mechanical components include a turbine made of durable, corrosion-resistant material, coupled with a generator via a pulley system for stable mechanical performance (Uchiyama et al., 2018; Gallego et al., 2021). A transparent acrylic cover encloses the water cycle system, allowing students to observe the energy conversion process clearly. An integrated water

reservoir and closed-loop circulation system further support efficient laboratory use.

Furthermore, this trainer is constructed upon a robust framework equipped with mobility wheels to facilitate transportation and incorporates comprehensive safety and protection components to ensure secure operational conditions. This evaluation confirms that the Pico Hydro trainer demonstrates not only superior technical performance but also exhibits strong alignment with educational requirements by providing a practical, safe, and contextually relevant learning platform for engineering students. The integration of these design features establishes a comprehensive educational tool that effectively bridges theoretical knowledge with hands-on practical experience in sustainable energy systems.

Media validation was carried out by material experts and media experts and was continued with user trials (students). Table 5 summarizes the average scores from each group and their corresponding categories.

Table 5. Expert Assessment Results

Response	Value	Criteria
Material Expert	3.60	Very Feasible
Media Expert	3.50	Very Feasible
User	3.56	Very Feasible
Total Average	3.55	Very Feasible

The validation results from material experts showed an average value of 3.60 with the category of "very feasible". The experts stated that the media was in accordance with the learning objectives and relevant to the needs of the practicum, although there were several minor aspects that were suggested for further development. Validation from media experts produced an average value of 3.50 with the same category and they suggested that the media be equipped with a more comprehensive user guide. In response to this, the researcher added a guidebook and video tutorials so that the use of the trainer was easier for students to understand.

Furthermore, the user response test involving students of the Electrical Engineering Education Study Program, UNIMED, produced an average value of 3.56 with the category of "very feasible". Students assessed that this trainer not only helped them understand the basic concepts of renewable energy generation but also improved their practical skills in measuring and analyzing energy system parameters.

These results indicate that the developed Pico Hydro trainer is suitable for use as a learning medium for renewable energy practicums. With a learning by doing-based approach, this tool can bridge theory and practice, while enhancing students' learning experiences actively and contextually. The integration of a closed

water circulation system also makes this trainer efficient and environmentally friendly for repeated laboratory use.

To assess the impact of the trainer on students' cognitive learning, a pre-test and post-test were administered. The results are visualized in Figure 9, indicating the improvement in students' scores after using the trainer.

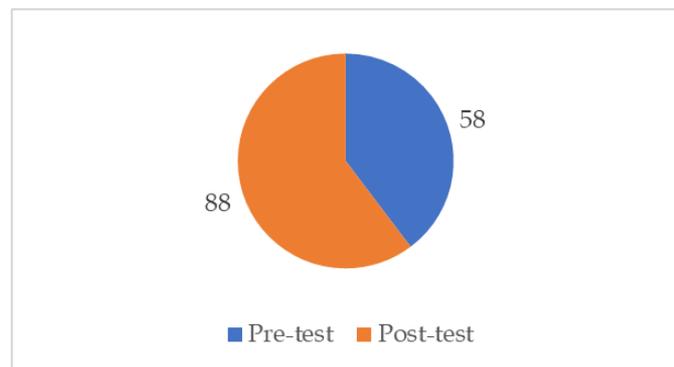


Figure 9. Test result graph

The average score obtained by students before the implementation (pre-test) was 58, and it increased to 88 after the learning activities using the trainer (post-test). According to the criteria of learning improvement effectiveness, a score of 71.4% is considered effective, as it exceeds the threshold for moderate effectiveness ($\geq 56\%$). This indicates that the use of the pico-hydro trainer significantly enhances students' cognitive understanding, particularly in the context of renewable energy systems (Rahayu & Windarta, 2022; Haryanto et al., 2024). These findings suggest that the trainer is not only valid and practical but also effective in fostering conceptual mastery in technical learning environments.

Conclusion

The development of the pico-hydro trainer has proven to be valid, practical, and effective as a learning tool for renewable energy practicum. Validation results from media and material experts, as well as student feedback, yielded an average score of 3.55, classified as "very feasible." Functionally, the trainer performed well under laboratory test conditions, generating up to 22V at 576 RPM. Furthermore, the cognitive learning outcomes of students improved significantly, as reflected by an N-Gain score of 0.714 (71.4%), which is categorized as effective. These findings indicate that the pico-hydro trainer successfully enhances students' understanding and skills in renewable energy systems, and is suitable for broader implementation in technical education settings. Additionally, as Indonesia moves toward integrating smart grid technologies to optimize distributed renewable energy systems, such trainers

serve as foundational tools in preparing future professionals.

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Author Contributions

This article was prepared by six authors, namely A.S., D.H.S, L.S, R.A.A.L, D.Y.N and R.N.T. All author members worked together at every stage of research and preparation of this article. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest

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