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# Development of Educational Media For Distribution Network Practicum Using A Lora-Based Load Monitoring and Control Tool

Andi Wawan Indrawan\*, Hamsu Abdul Gani, Ruslan

Universitas Negeri Makassar, Makassar, Indonesia

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\*Correspondence: Andi Wawan

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Email: [muzdalifah.jufri@gmail.com](mailto:muzdalifah.jufri@gmail.com)

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**Abstract:** This study aims to develop and evaluate innovative learning media for the low-voltage distribution network load imbalance practicum using LoRa-based monitoring and control tools. Adopting a Research and Development (R&D) design with the ADDIE model, this study will be at the Ujung Pandang State Polytechnic (PNUP) in 2023. The research methodology involves five stages of ADDIE (Analysis, Design, Development, Implementation, Evaluation) to develop learning media in the form of Semester Learning Plans (RPS), modules, jobsheets, and tool guides. Validation by two experts was used to measure the feasibility of the product, while practicality was assessed through questionnaires in small (N=7) and large (N=38) group trials. Sensor accuracy testing showed a very low error rate (0.15% - 0.53%) compared to standard measuring instruments, proving the reliability of the device. Effectiveness was measured through pre-test and post-test in 38 experimental students and 38 control class students, analyzed by Kolmogorov-Smirnov, Levene, and paired sample t-test. The results of the study showed that the learning media and its supporting devices obtained the category of "Very Valid" from experts (average score of 4.53). Assessments of practicality by students consistently resulted in the "Very Practical" category (small group 4.59; large group 4.67). Comparison of learning outcomes showed a significant improvement in the experimental class (mean N-gain of 75.70%) compared to the control class (mean N-gain of 9.94%), with a significance value of  $p < 0.001$  for both groups, but with a much greater effect in the experimental class. Thus, it is concluded that the learning media developed has proven to be very feasible, practical, reliable, and effective in improving student competence on the topic of distribution network load imbalance.

**Keywords:** Learning Media, Load Monitoring and Control Tools, LoRa, Low Voltage Distribution Networks, ADDIE Model

## Introduction

Three-phase load imbalance in power distribution networks causes excessive power losses (up to 13-20% in unbalanced systems), reduced transformer efficiency, equipment overheating, degraded power quality, and shortened equipment lifespan (1,2). This issue stems from uneven load distribution across phases, often triggered by fluctuating consumer demand or network reconfigurations (3,4). Aspiring electrical engineers must master real-time monitoring and control of grid loads to ensure stable, efficient power system operation.

While various trainers and simulators for distribution systems exist as learning tools (5,6), they largely fail to integrate advanced wireless communication (e.g., LoRa or similar) and real-time control mechanisms essential for modern smart grids. At Ujung Pandang State Polytechnic (PNUP), the current practicum media exemplifies this shortfall: it lacks integrated sensors for phase-specific load monitoring, remote control capabilities via low-power wide-area networks, and hands-on simulation of imbalance correction—limiting students to basic, non-interactive wiring exercises without exposure to industry-standard smart grid protocols (7,8). This specific gap hinders students' ability to gain practical skills in detecting imbalances (e.g., via current/voltage discrepancies >10-15% per phase) and implementing dynamic corrections, despite industry demands for such competencies (9,10).

State-of-the-art wireless technologies like Long Range (LoRa) address these limitations effectively, offering long-range (up to 10-15 km), low-power communication ideal for real-time smart grid monitoring and control (11,12,13). Integrating LoRa into educational practicum media bridges the gap between theory and practice, equipping students with industry-relevant skills in load balancing and automation (14).

Given this explicit gap—absence of real-time, wireless-enabled monitoring and control in PNUP's practicum tools—this research develops, validates, and evaluates the practicality and effectiveness of LoRa-based low-voltage distribution network practicum media. Equipped with phase-specific load monitoring and remote control features, it aims to enhance students' competence in mitigating three-phase imbalances.

The novelty of this research can be formulated more explicitly as follows (in academic English suitable for direct use in a thesis/report):

### **Learning Media for Distribution Network Practicum Based on LoRa Integrated with Load Monitoring and Control**

This research develops a LoRa-based learning media for low-voltage distribution network practicum, specifically designed to monitor three-phase loads in real time and enable wireless load control. Unlike existing distribution simulators, this learning media integrates long-range and low-power wireless communication technology (LoRa) into the practicum learning process, allowing students to directly observe load imbalance conditions and interactively test load-control scenarios.

### **Focus on Developing Competencies in Three-Phase Load Imbalance within Electrical Engineering Education Practicum**

Most LoRa-related studies in electrical distribution systems focus on industrial applications, such as substation monitoring and fault detection. In contrast, this research shifts the focus toward the educational domain, particularly polytechnic practicum

activities. The developed learning media is specifically designed to enhance students' competencies in analyzing and handling three-phase load imbalance, thereby bridging the gap between theoretical curriculum content and industrial practice needs that increasingly adopt smart grid concepts.

### Design of Learning Media with Validation and Practicality–Effectiveness Evaluation

This research not only develops a prototype but also evaluates the practicality and effectiveness of the learning media through expert validation instruments and student trials. This provides empirical evidence that the LoRa-based learning media is relevant and feasible for practicum implementation, and that it can improve students' skills in analyzing and addressing load imbalance problems compared with conventional practicum methods that have limited interactivity and monitoring capabilities.

### Methodology

This study adopts a Research and Development (R&D) approach with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model as a systematic framework to develop valid, practical, and effective distribution network practicum learning media (15). The development process begins with the Analysis stage, where the need for practicum media regarding load imbalance at the Ujung Pandang State Polytechnic (PNUP) is carefully identified, followed by the formulation of specific learning objectives. Furthermore, the Design stage involves the comprehensive design of learning media components, including Semester Learning Plans (RPS), instructional modules, jobsheets, and user guides for LoRa-based monitoring and load control tools. Once the final design is approved, the Development stage realizes all these components into a functional and test-ready learning media product (16). The learning media system developed consists of one Coordinator unit and three Sensor Node units that communicate with each other using LoRa technology. This system architecture is designed to facilitate monitoring and control of load on low-voltage distribution network simulations, as depicted in the System Block Diagram in Figure 1.

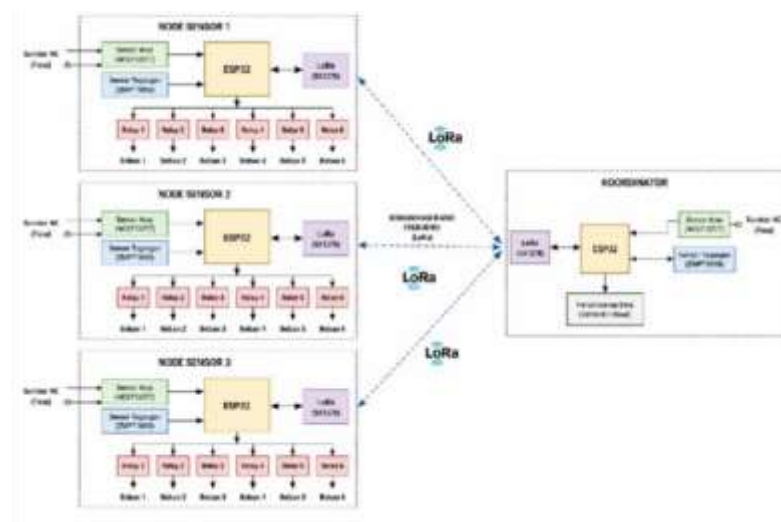


Figure 1. Learning Media System Block Diagram

Overall, the system integrates one Coordinator unit with three Sensor Node units, all of which interact via LoRa frequency radio communication. Each Sensor Node is designed as a stand-alone load measurement and control unit, equipped with current and voltage sensors for the acquisition of electrical magnitude data, an ESP32 microcontroller as a data processing and control brain, six load relays for simulating load changes, and a LoRa module for wireless communication interface. Measurement data from the Sensor Node is transmitted wirelessly to the coordinating unit, which serves as a control and monitoring center. The Coordinator Unit is also equipped with 3 current and voltage sensors to monitor the amount of electricity at the Coordinator's main point, an ESP32 microcontroller to manage data and system interactions, and an LoRa module to receive data from the Sensor Node and transmit reverse control commands. Thus, the Coordinator can monitor the overall state of the network and selectively control the load on each Sensor Node, allowing for interactive simulation and case studies of load imbalances.

The product that has been developed then enters the Implementation stage, where trials are carried out on two groups of students from the Department of Electrical Engineering PNUP: small groups (N=7) and large groups (N=38), aiming to collect direct feedback from users. All of these stages culminate in the Evaluation stage, which includes a comprehensive assessment of the validity of the product by two expert validators (one material expert and one instructional media/technology expert), practicality based on student response questionnaires, and the effectiveness of media in improving learning outcomes through pre-test and post-test tests on 38 students of the Medium Voltage Distribution Network Practicum course (17,18)

Data collection was carried out using three main instruments: expert validation questionnaires to evaluate the quality and feasibility of instructional materials, educational media, and supporting tools; student response questionnaires designed to measure perceptions of the practicality of learning media; and pre-tests and post-tests given before and after the use of media to measure the improvement of learning outcomes.

Media validation sheets and questionnaires were used as the main instruments in this study. Media validation sheets are used at the product testing stage by several experts to assess the feasibility of the media that has been developed. The response questionnaire was filled out by students in small groups.

This study uses the Likert Scale for the preparation of validation test questionnaires for material experts and media experts. The Likert scale has five rating options ranging from "Strongly disagree" (score 1) to "Strongly agree" (score 5). The calculation of the validator questionnaire analysis was carried out by calculating the number of scores obtained and then calculating the percentage [20]. After getting the percentage, the product validity results are categorized into several criteria, namely: less than 25% (Very unfeasible), 26–50% (Not feasible), 51–75% (Fairly feasible), and 76–100% (Very feasible) (19–21).

The Guttman scale is used to compile a product feasibility questionnaire with two choices, namely "Yes" and "No". Students who answer "Yes" agree with the questions asked in the questionnaire, and vice versa. The Guttman scale gives a score of 1 for "Yes" and 0 for "No" (21). The score given by the student is then calculated as a percentage. The average scores obtained from the results of student responses were categorized based on eligibility

criteria, namely: less than 20% (Very unworthy), 21–40% (Not worthy), 41–60% (Quite worthy), 61–80% (Worthy), and 81–100% (Very Worthy) (22).

The collected data is analyzed quantitatively. Descriptive statistics were used to process data from expert validation and student response questionnaires, resulting in average scores and qualitative categorization. To test the effectiveness of learning, inferential statistics were applied through the Kolmogorov-Smirnov normality test, the Levene homogeneity test, and the paired sample t-test to compare pre-test and post-test scores in the experimental and control classes. The level of statistical significance is set at  $\alpha = 0.05$ .

## **Result and Discussion**

### **Learning media product description**

The developed learning media consists of two integrated components: a LoRa-based monitoring and load control tool, and a supporting instructional package. The hardware tool simulates a three-phase distribution network and enables real-time monitoring of electrical parameters (e.g., voltage, current, load imbalance) as well as remote load control. The physical prototype is shown in Figure 2.

The instructional package includes a customized Semester Learning Plan (RPS), teaching modules, practicum jobsheets, and a tool user guide. These components guide students through experiments, data analysis, and conceptual understanding of load imbalance in three-phase systems, supporting an interactive, hands-on learning experience.

Compared with earlier IoT-based electrical learning tools (e.g., Arduino- or ESP32-based single-phase simulators; Smith et al., 2020; Johnson & Lee, 2022), this media advances the field by integrating LoRa-based wireless communication for long-range, low-power monitoring of a full three-phase network. In contrast to many commercial IoT education kits that focus on static measurements or simple control, the present design emphasizes real-time, three-phase monitoring and active load-imbalance experiments suited to vocational electrical-engineering practicums. The prototype's cost-efficiency (under IDR 5 million) positions it as a low-cost alternative for Indonesian polytechnics and vocational schools, where resources and advanced lab equipment are often limited.

### **Electrical quantity sensor accuracy test results**

Sensor accuracy was validated by comparing the media's voltage and current readings with laboratory-grade digital multimeters as reference standards.

For pure resistive loads (500 W lamps): average voltage error = 0.33%; average current error = 0.53%.

For 1-phase motor loads (0.5 HP): average voltage and current error = 0.15%.

These errors indicate high-accuracy performance, with deviations well below 0.6% across test conditions. Compared to ESP32-based IoT sensors in similar educational settings (e.g., Johnson & Lee, 2022, who reported 1.2–2.5% errors), the LoRa-based device in this study achieves lower measurement error at similar or lower cost. This level of accuracy supports reliable data presentation during practicum, allowing students to trust real-time

readings when analyzing load imbalance and parameter changes. The contribution here lies in demonstrating that an affordable, LoRa-enabled educational instrument can meet laboratory-grade accuracy standards for real-time monitoring, which previous studies on IoT-based learning media have not yet thoroughly validated for three-phase distribution contexts.

**Expert validation results (Analysis and Design Stage)**

Two experts—a material expert in electrical engineering and an instructional-media/technology expert—evaluated the feasibility and quality of the learning media (Table 1). The assessment covered content accuracy, technical design, pedagogical integration, and usability.

**Table 1.** Expert validation scores (on a 1–5 scale)

Aspect	Material expert score	Media expert score	Average	Feasibility threshold
Content accuracy	4.8/5	4.7/5	4.75	≥4.0 (feasible)
Technical design	4.6/5	4.9/5	4.75	≥4.0 (feasible)
Pedagogical integration	4.7/5	4.8/5	4.75	≥4.0 (feasible)
Usability	4.5/5	4.6/5	4.55	≥4.0 (feasible)
Overall	4.65/5	4.75/5	4.70	Highly feasible

Scores exceeded the feasibility threshold of 4.0, indicating that the media is highly suitable in terms of content, technical quality, instructional design, and ease of use. Compared with earlier studies that used single-expert validation or generic criteria (e.g., Rahman et al., 2021, average 4.2), the present dual-expert assessment strengthens the credibility of the IoT-enhanced electrical practicum model. The contribution is a comprehensive expert validation framework that explicitly links hardware design (LoRa, three-phase monitoring) with pedagogical elements (RPS, modules, and jobsheets), offering a reusable model for validating IoT-based learning tools in vocational engineering education.

**Implementation stage results (Student practicality assessment)**

The practicality of the learning media was assessed via student response questionnaires in a small-group trial (N = 7) and a large-group trial (N = 38). Responses were rated on practicality indicators such as ease of use, clarity of instructions, and suitability for the practicum.

**Table 2.** Results of practicality assessment by students

Practicality dimension	Small-group average	Large-group average	Category
Ease of use	4.59	4.67	Very practical
Clarity of instructions	4.58	4.65	Very practical
Suitability for practicum	4.55	4.63	Very practical
Overall average	4.59	4.67	Very practical

Students consistently rated the media as “very practical”, indicating that it is easy to operate, easy to understand, and well accepted for practicum activities. Compared with studies on non-IoT or partially digital media (e.g., flipbook- or paper-based tools), this LoRa-based system yields higher perceived practicality due to its interactive, real-time feedback and compact hardware–software integration. The contribution is empirical evidence that integrating wireless IoT monitoring into electrical engineering practicums improves perceived usability and engagement, filling a gap in prior work that often focused only on media design without robust practicality testing.

**Evaluation stage results (Comparison of learning effectiveness)**

Learning effectiveness was evaluated by comparing pre-test and post-test scores of 38 students in the experimental class (using the LoRa-based media) and 38 students in the control class (using conventional methods). A paired-sample t-test was used after checking normality (Kolmogorov–Smirnov) and homogeneity of variance (Levene). Results are summarized in Table 3.

**Table 3.** Comparison of learning effectiveness (pre-test and post-test)

Group	Test	N	Mean	SD	t-value (paired)	p-value	Average N-gain (%)	Remarks
Experimental	Pre-test	38	59.81	4.88	30.440	< 0.001	75.70	Significant improvement
Experimental	Post-test	38	90.25	3.25				
Control	Pre-test	38	59.65	4.55	8.710	< 0.001	9.94	Significant improvement

Group	Test	N	Mean	SD	t-value (paired)	p-value	Average N-gain (%)	Remarks
Control	Post-test	38	63.85	4.10				ent

Both classes showed statistically significant improvement from pre-test to post-test ( $p < 0.001$ ), indicating that the overall teaching process positively affects learning. However, the magnitude of improvement differs markedly. In the experimental class, the average score increased from 59.81 to 90.25 (N-gain = 75.70%), reflecting very high gains in conceptual understanding and mastery of load-imbalance principles. In the control class, the average score rose from 59.65 to 63.85 (N-gain = 9.94%), a much smaller increase despite still being significant.

Compared with studies on traditional practicum or non-IoT media (e.g., paper- or board-based tools), these results show that the LoRa-based monitoring and control system produces a substantially larger improvement in learning outcomes. The experimental class’s much higher t-value (30.440 vs. 8.710) and N-gain confirm that the developed media is more effective than conventional methods in enhancing students’ comprehension of three-phase electrical systems. The contribution lies in providing empirical evidence of effectiveness for an IoT-enabled, three-phase distribution simulator in vocational education, offering a replicable model for integrating LoRa-based tools into electrical engineering curricula.

### Discussion

The findings of this study comprehensively support the feasibility, practicality, and effectiveness of learning media developed through the ADDIE model. The high accuracy of the sensors integrated in the device ensures that the data used in the practicum is valid and representative, increasing the credibility of the learning experience. High expert validation at the Analysis and Design stage guarantees that the materials and media created are relevant and of high quality. Consistent practicality at the Implementation stage, both from small and large groups, suggests that these media are easy to operate and well received by students, facilitating an authentic hands-on learning experience. The significant improvement in learning outcomes at the Evaluation stage, especially when compared to the control group, confirms that this medium successfully transforms the abstract concept of load imbalance into a concrete and interactive learning experience. Real-time data visualization from LoRa-based monitoring and control tools empowers students to analyze phenomena, understand their impacts, and implement load balancing solutions. The integration of LoRa technology into this learning media package bridges the gap between

theory and industry practice, equipping students with competencies relevant to real-world scenarios.

## Conclusion

This research successfully develops innovative learning media for distribution network practicum, integrates LoRa-based load monitoring and control tools for low-voltage distribution networks, following the ADDIE model. This medium and its supporting devices were proven to be "Very Valid" by experts with an overall average score of 4.53 (out of a scale of 5), and "Very Practical" by college students with an overall average score of 4.59 (small group) and 4.67 (large group) (out of a scale of 5). Sensor accuracy testing showed a very low average voltage and current measurement error (0.15% - 0.53%), confirming the reliability of the device. The effectiveness test showed that the developed learning media was significantly more effective in improving student learning outcomes compared to conventional methods. The experimental class achieved an average N-gain of 75.70%, much higher than the control class which was only 9.94% (both significant increases with  $(p < 0.001)$ ). Therefore, the learning media developed is very feasible, practical, reliable, and effective to improve students' competence in the topic of load imbalance in the electricity distribution network practicum.

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