Research Article

Enhancing Wireless Communication Learning Through Interactive Hands-On Trainer Applications Using 433 MHz LoRa Networks

Aslinda Zamah Shari[1*], Fazida Adlan[2] and Guan Chengg Wong[3]

[1] Politeknik Sultan Salahuddin Abdul Aziz Shah; aslinda.psa@gmail.com; 0009-0007-0405-0071
[2] Politeknik Sultan Salahuddin Abdul Aziz Shah; fazida@psa.edu.my; 0009-0008-4800-3645
[3] Politeknik Sultan Salahuddin Abdul Aziz Shah; guanchengg.wong@gmail.com; 0009-0000-3292-2024

* Correspondence: aslinda.psa@gmail.com; +6012-3352263.

Abstract: *This study presents an innovative hands-on trainer using 433 MHz LoRa networks to enhance learning in the DEP50063 Wireless Communication course at Politeknik Sultan Salahuddin Abdul Aziz Shah. The trainer addresses the challenge of outdated lab equipment, which limits student's understanding of key wireless concepts such as frequency, distance, low power and environmental impact. Designed to link the gap between theory and practice, the trainer integrating ESP32 boards, LoRa SX1278 modules and adjustable antennas to provide an interactive and practical learning experience. The main objectives are to improve student engagement, develop skills in wireless IoT technology and make practical sessions more efficient for lecturers. Positive feedback from students and lecturers highlights significant improvements in understanding and applying wireless communication concepts, meeting Course Learning Outcome 2 (CLO 2) and Program Learning Outcome 5 (PLO 5). The trainer also demonstrates strong commercialization potential, being cost-effective, scalable and applicable to various industries such as agriculture and smart cities. In conclusion, the 433 MHz LoRa trainer is a valuable educational tool that equips students with the skills needed for real-world challenges while enhancing teaching and learning efficiency.*

Keywords: LoRa networks; wireless communication; IoT technology; hands-on trainer; educational innovation.

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1. INTRODUCTION

Hands-on learning is one of the important elements to helping students understand theory with practice, especially in wireless communication courses. To improve the learning experience, a hands-on trainer by using 433 MHz LoRa networks was created for the DEP50063 Wireless Communication course. This trainer was introduced by Electrical Engineering Department, Politeknik Sultan Salahuddin Abdul Aziz Shah to semester 5 students in the Diploma in Electronic Engineering (Communication) program during session I 2024/2025. The trainer focuses on practical learning for Topic 1.0: Wireless Communication Systems and helps students achieve Course Learning Outcome 2 (CLO 2) and Program Learning Outcome 5 (PLO 5). (PSA, 2024)

The trainer was developed to solve the problem of outdated lab equipment, which may limit students to exposure to modern wireless technologies. By using this new tool, the traditional one-way teaching method is improved to make learning more interactive. Students will explore the main wireless communication topics like frequency, distance, low power and environmental factors. The trainer helps students understand these concepts better by allowing them to practice by applying what they learn in real-world situations. In addition, this trainer also makes teaching and learning sessions easier for lecturers by providing updated tools and resources. It helps practical sessions run more smoothly and efficiently, allowing students to develop skills in wireless IoT technologies. Overall, this hands-on trainer helps students connect theory with practice and enhances their understanding of wireless communication systems.

LoRa (Long Range) is a wireless communication technology widely recognized for its role in advancing Internet of Things (IoT) applications. It is under the category of Low Power Wide Area Networks (LPWANs) and is optimized for long-range communication with low energy consumption. LoRa operates in unlicensed frequency bands (e.g., 433 MHz, 868 MHz and 915 MHz), making it accessible and cost-effective for diverse applications (Kulkarni, Hakim, & Lakas, 2019). The technology leverages chirp spread spectrum (CSS) modulation, enabling robust and interference-resistant communication even in challenging environments. LoRa allows users to balance data rate and range by configuring parameters like spreading factors (SF), bandwidth, and coding rate, which makes it versatile for urban, suburban, and rural deployments (Vazquez-Rodas et al., 2020; Anjum et al., 2020).

Applications of LoRa span various fields, including environmental monitoring, smart agriculture, healthcare, and urban planning. Its star network topology simplifies deployment, where end devices communicate with centralized gateways that relay data to servers (Azmi et al., 2018). The ability to function effectively in GPS-denied environments has further cemented LoRa's position as a critical enabler of IoT innovations (Tan et al., 2019). Despite its advantages, LoRa's limitations, such as low data rates and susceptibility to congestion in dense networks, necessitate careful planning and configuration during deployment (Madona et al., 2022). Continuous research and development in LoRa-based solutions are shaping its integration into next-generation IoT ecosystems, promising enhanced connectivity and resource efficiency (Anjum et al., 2020).

2. METHOD & MATERIAL

This study follows a clear and organized process to develop and test the hands-on trainer using 433 MHz LoRa networks. The steps are as follows:

1. Literature Review & Discussion: A review of existing studies was conducted to understand the challenges in teaching wireless communication and the potential of LoRa technology. Discussions with educators and industry experts helped refine the project goals.

2. Problem Definition & Objectives: Problems, such as outdated lab equipment and limited student engagement, were identified in this stage. Specific objectives were set to solve these issues by linking theory to practice using the hands-on trainer.

3. System Design and Planning: The trainer system's design was planned, including selecting components like ESP32 boards and LoRa SX1278 modules, and creating a blueprint for their integration.

4. Software/Hardware Configuration: The hardware and software were set up, including programming the ESP32 boards, configuring the LoRa modules, and ensuring all components work together effectively.

5. Development of Prototype: A working prototype of the trainer was created, combining the hardware and software components to meet the educational objectives.

6. Testing and Validation: The prototype was tested to ensure it performed as expected, was reliable, and easy for students and lecturers to use. The system was checked to confirm it met the course learning goals.

7. Data Collection and Analysis: Feedback and performance data were collected from students and lecturers during practical sessions. The data was analysed to measure how well the trainer improved learning and engagement.

8. Evaluation and Documentation: The trainer was evaluated for its effectiveness in meeting CLO 2 and PLO 5. All processes, results, and recommendations were documented for future reference and improvements.

This innovation aims to enhance teaching and learning by integrating ESP32 microcontrollers and LoRa SX1278 modules to facilitate real-time wireless communication supported by Arduino IDE application. Table 1 shows the main components, quantity needed, their functions in this lab setup and its explanation and potential benefits in this innovation (Sanchez-Iborra, Sanchez-Gomez, Ballesta-Viñas, Cano, & Skarmeta, 2018) (Kwasme & Ekin, 2019) (Madona et al., 2022) (Madona, Efrizon, Nasution, Putri, & Devy, 2023).

Table 1 : Main Components, Its Quantity Needed, Function and Explanation

Component	Quantity Needed	Main Function	Explanation and Benefits
ESP32 Boards	2	Used as transmitter and receiver for data communication.	These boards are Wi-Fi and Bluetooth-enabled microcontroller units that support wireless communication.
LoRa SX1278 Modules	2	Facilitates long-range wireless communication at 433 MHz frequency.	These modules operate at a frequency of 433 MHz, which is suitable for long-range, low-power communication in IoT (Internet of Things) applications. The two LoRa modules were connected to the ESP32 boards, allowing one to transmit data and the other to receive it. The use of LoRa technology ensures communication over long distances, even in remote or obstructed environments.

Antennas with Varying Gain	3 (3 dBi, 6 dBi, 12 dBi)	Used to test the effect of antenna gain on signal strength and communication range.	The gain of an antenna refers to its ability to focus the radio waves in a particular direction, improving the signal strength and range in that direction. A higher dBi (decibels over isotropic) value indicates a more focused and directional antenna, potentially increasing the range and reliability of the communication. By using antennas with varying gains, the experiment could test how different levels of antenna gain affect the overall communication range and signal strength.
Arduino IDE	1	Used for writing and uploading code to the ESP32, as well as monitoring data.	It provides a user-friendly platform for implementing the logic to send and receive data. Additionally, the IDE enables monitoring of the data transmission, ensuring that the communication between the ESP32 boards and LoRa modules was functioning as expected.

The purpose of the two circuit connections in this innovation setup is to establish a reliable and efficient communication link between the transmitter and receiver modules. In this configuration, the first circuit connection involves the ESP32 board acting as the transmitter. It is connected to a LoRa SX1278 module, which transmits data over long-range wireless communication using the 433 MHz frequency. This connection allows the ESP32 to send signals or information to the receiver.

The second circuit connection involves the ESP32 board acting as the receiver, which is connected to another LoRa SX1278 module. This receiver circuit enables the ESP32 to capture the transmitted data from the first circuit, processing the incoming signals and facilitating real-time communication. The interaction between these two circuit connections enables effective wireless data transfer, making the setup ideal for demonstrating practical communication systems and enhancing student's learning experiences in wireless communication technologies.

By using two separate circuits, one for transmission part and one for reception part, students can explore the basic concepts of how data is transferred in wireless systems and how different components, like the LoRa modules, interact in a practical IoT environment compared with others like RFID modules.

3. FINDINGS

The findings from this innovation in teaching and learning are based on a series of hands-on activities where students engaged in LoRa wireless experiments using ESP32 boards and LoRa SX1278 modules. The students participated in transmitting and receiving data over long-range wireless communication, while experimenting with different antenna gains (3 dBi, 6 dBi, and 12 dBi). The experimental results, particularly focusing on RSSI variations, showed that higher antenna gains significantly improved signal strength and communication range. Feedback from both students and staff was positive, with students noting that the practical nature of the activity helped them better understand theoretical concepts, while staff highlighted the value of the exercise in enhancing student's technical skills in wireless communication systems.

3.1 Hands-On Learning

In this hands-on activity, students will be introduced to the components needed to set up a wireless communication system using LoRa technology. They will first receive individual parts such as ESP32 boards, LoRa SX1278 modules, and antennas, which are not connected. With guidance from the instructor, students will follow simple steps to connect the components correctly. Once the components are set up, students will test the signal strength (RSSI) in different conditions. They will start by measuring RSSI at different distances (5m, 7m, 10m, 12m, and 15m) in both Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions, comparing the results indoors and outdoors. This will help them understand how distance and obstacles affect signal strength.

Next, students will test the system outdoors in area of Politeknik Sultan Salahuddin Abdul Aziz Shah over longer distances, such as from the Electrical Engineering Department (JKE) Foyer to Commerce Department (JPG), JKE Foyer to Civil Engineering Department (JKA), and Center for Medical Electronic Technology (CMET) to Lab of Data Communication (MB 022). They will also check how different antenna types (3 dBi, 6 dBi, 12 dBi) affect signal strength at these distances. By doing these tests, students will see how antenna gain and distance impact the wireless range, especially in Line of Sight (LOS) conditions. Additionally, they will compare the performance with different antenna setups, such as using 3 dBi for the transmitter and 6 dBi for the receiver.

Through these activities, students will gain practical experience with wireless communication systems. They will learn how factors like the environment and antenna choice affect signal strength, helping them understand how these systems work in the real world.

3.2 Analysis and Insights: Student-Collected Results Using the Developed Wireless Communication Trainer

The Table 2 and Figure 1 shows that signal strength reading and analysis based on indoor and outdoor with LOS and NLOS. The signal strength (RSSI) decreases as the distance increases in both indoor and outdoor environments, with significant differences between Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) scenarios. Indoor LOS conditions provide better RSSI values compared to NLOS, as physical obstructions weaken the signal. Outdoor LOS conditions also perform better than outdoor NLOS, with outdoor NLOS showing the weakest signal strength due to environmental factors such as obstacles and interference.

Table 2 : Signal Strength Readings Based on Indoor and Outdoor with LOS and NLOS

Distance (m)	RSSI (dBm)			
	Indoor		Outdoor	
	LOS	NLOS	LOS	NLOS
5	-61	-62	-59	-84
7	-60	-73	-66	-88
10	-68	-72	-71	-85
12	-71	-74	-68	-95
15	-81	-79	-75	-89

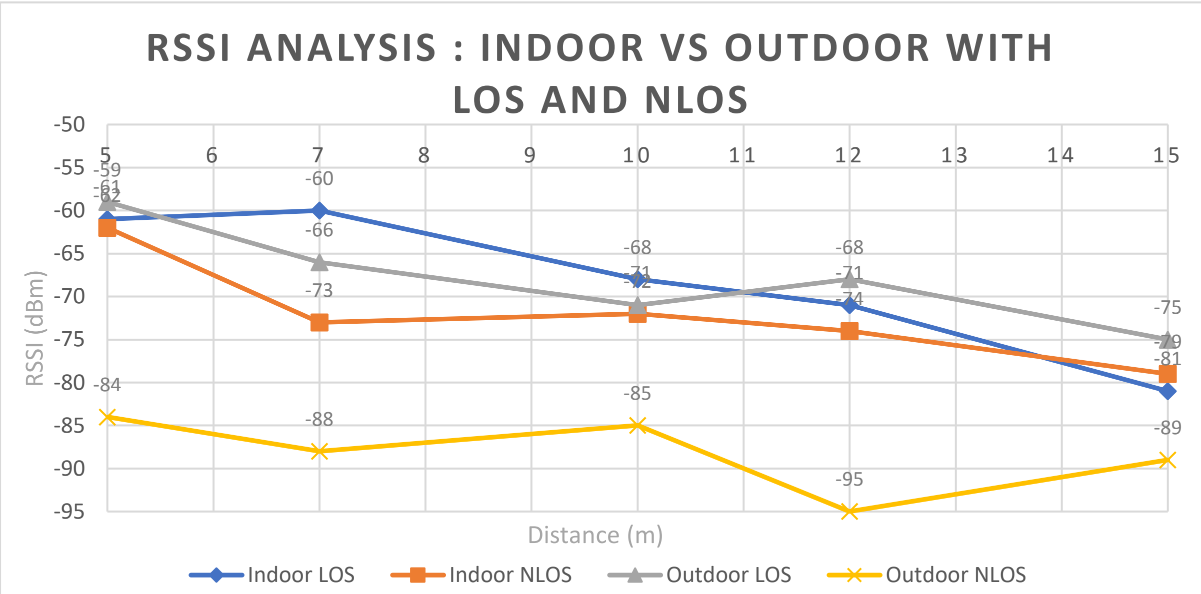

Figure 1 : Signal Strength Analysis Based on Indoor and Outdoor with LOS and NLOS

The Table 3 shows outdoor signal performance based on distance and antenna specifications. Higher-gain antennas significantly increase the communication range, as seen with a 12 dBi antenna achieving 305.5 meters with an RSSI of -98 dBm. Lower-gain antennas, such as 3 dBi, achieve shorter distances, with a maximum of 22 meters at an RSSI of -77 dBm. This indicates that antenna gain is a crucial factor in improving communication range in outdoor environments, though environmental conditions still influence overall performance.

Table 3 : Outdoor Signal Performance Based on Distance and Antenna Specifications

Location	Antenna Type	Outdoor (LOS)	
		Distance (m)	RSSI (dBm)
JKE Foyer to JPG	3 dBi / 3 dBi	22	-77
JKE Foyer to JKA	3 dBi / 3 dBi	44	-93
CMET to MB 022	3 dBi / 3 dBi	48	-97
Lab Wiring to Bus Station PSA	12 dBi / 3 dBi	305.5	-98

The Table 4 shows performance metrics : RSSI and maximum distance based on antenna gain. It highlights the relationship and compare between antenna gain, maximum distance, and RSSI. When both the transmitter and receiver use 3 dBi antennas, the maximum range achieved is 159 meters with an RSSI of -100 dBm. As the gain increases, the communication range extends significantly. For example, a 12 dBi transmitter paired with a 6 dBi receiver achieves a range of 405.5 meters, though the RSSI slightly worsens to -108 dBm, showing that higher-gain antennas enhance range but with diminishing signal strength at extreme distances.

Table 4 : Performance Metrics : RSSI and Maximum Distance Based on Antenna Gain

Antenna Gain		Maximum Distance (m)	RSSI (dBm)
Transmitter	Receiver		
3 dBi	3 dBi	159	-100
6 dBi	3 dBi	243	-103
12 dBi	6 dBi	375	-110
12 dBi	6 dBi	405.5	-108

3.3 Students and Staffs Feedback

The feedback collected from students and lecturers evaluates the effectiveness of the LoRa trainer as a teaching tool in wireless communication. The analysis focuses on four key questions:

1. How effective is the trainer in teaching and learning for wireless practical work?
2. Does the trainer help to encourage students to explore and expand their knowledge?
3. How effective is the trainer in helping students bridge the gap between theory and practice?
4. How effective is the trainer in enhancing students' understanding of wireless communication concepts?

The overall results reveal a highly positive reception, with many students and lecturers strongly agreeing that the LoRa trainer effectively meets its objectives. Students expressed enthusiasm, with strong agreement on its role in improving practical learning, advance knowledge expansion, bridging theory and practice and deepening understanding of wireless concepts. Lecturers also provided supportive feedback, though slightly more moderate. These findings emphasize the trainer's success in delivering an engaging and impactful educational experience.

Figure 2 presents the response statistics for the first question (the effectiveness of the trainer in teaching and learning for wireless practical work). Most of both students and lecturers strongly agree or agree that the LoRa trainer is effective in teaching and learning for wireless practical work. Students show strong support, with 60 expressing strong agreement. While lecturers also view the trainer positively, their responses are somewhat less emphatic, with a small proportion (1) remaining neutral.

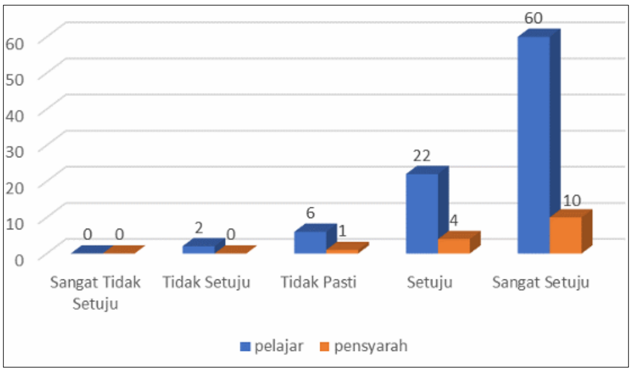

Figure 2 : Feedback for Survey Question 1

Figure 3 illustrates the response statistics for second question (the trainer helps to encourage student to explore and expand knowledge). Most students (85 out of 90) either strongly agree or agree that the trainer fosters exploration and knowledge expansion, reflecting a highly positive reception among students. Lecturers also largely support this view, with all 15 respondents either strongly agreeing or agreeing. The neutral and negative responses from students are minimal, indicating that the trainer is perceived as highly effective in promoting this educational objective.

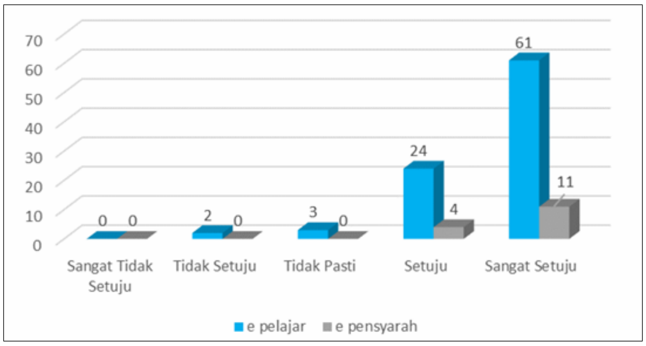

Figure 3 : Feedback for Survey Question 2

Figure 4 presents the response statistics for third question (the effectiveness of the trainer in helping students bridge the gap between theory and practice). A significant majority of students (81 out of 90) and all lecturers (15 out of 15) either strongly agree or agree that the trainer effectively bridges theoretical concepts and practical skills. The neutral responses from 9 students suggest that a small group may require additional support or training to fully benefit from the trainer. Notably, there are no instances of disagreement or strong disagreement, underscoring the widespread acceptance of the trainer's effectiveness in this regard.

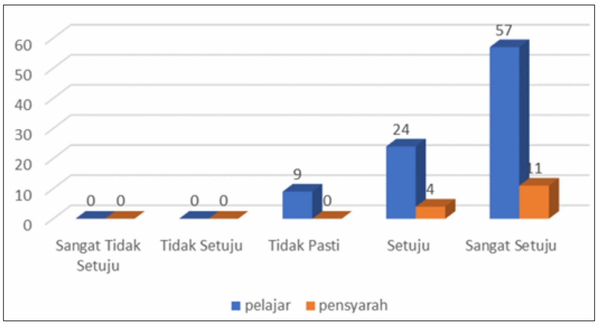

Figure 4 : Feedback for Survey Question 3

Figure 5 illustrates the response statistics for last survey question (the effectiveness of the trainer in enhancing students' understanding of wireless communication concepts). Most students (69 out of 90) and lecturers (12 out of 15) either strongly agree or agree that the trainer effectively enhances understanding of wireless communication concepts. However, a small percentage of students (13 neutral and 8 disagree) may not fully benefit from the trainer, indicating the potential need for additional support or adjustments to the training approach. The absence of strong disagreement suggests that the trainer is generally well-received and considered effective in this area.

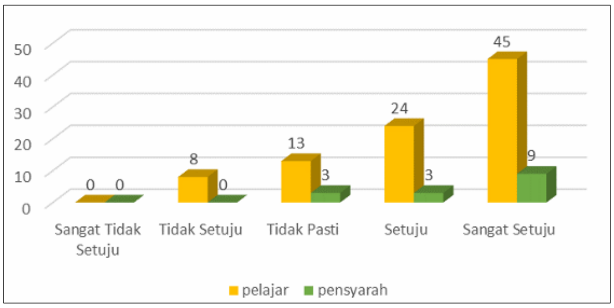

Figure 5 : Feedback for Survey Question 4

4. DISCUSSION

This study shows that using the 433 MHz LoRa Wireless IoT Technology Trainer as a teaching tool is very effective in helping students learn about wireless communication systems. By conducting hands-on activities with ESP32 boards, LoRa SX1278 modules and antennas of different gains (3 dBi, 6 dBi, and 12 dBi), students were able to understand how signal strength (RSSI) and communication range are affected by various factors.

The hands-on experiments demonstrated the effectiveness of higher-gain antennas in improving both communication range and RSSI. For example, a 12 dBi antenna achieved the longest communication distance of 405.5 meters. However, as the range extended to its limits, the RSSI reduced slightly due to signal attenuation. Students conducted tests under various conditions, including different distances and environments, both indoors and outdoors. Line-of-Sight (LOS) consistently provided stronger signal strength than Non-Line-of-Sight (NLOS) due to fewer obstacles and less interference. Outdoor NLOS testing showed the weakest signals, showing the impact of environmental factors on wireless communication. The hands-on nature of the activity helps students understand how antenna gain and environmental factors affect signal performance, providing practical highlighted into real-world wireless communication challenges.

Feedback from students and lecturers shows that the trainer's value in bridging the gap between theory and practice. Students found the activities highly effective in applying theoretical knowledge to practical scenarios and developing high technical skills for wireless IoT and communication systems. They gained a clear understanding of how signal strength is affected by distance, environment and antenna specifications.

Lecturers also agreed with the trainer being able to use and helping in simplifying the teaching process by reducing complex setup and allowing more time for meaningful discussions of key concepts. Both groups highlighted the importance of such innovations in improving education quality, particularly in preparing students for industry-specific roles. The results illustrate that the trainer's ability to deliver an engaging and impactful learning experience that connects theoretical principles with real-world applications.

In conclusion, the LoRa Wireless IoT Technology Trainer has proven to be a valuable educational tool. It enhances practical skills, improves student understanding, bridges the gap between theoretical and practical knowledge, and increases teaching efficiency. These impacts underline the trainer's effectiveness in preparing students for careers in the rapidly evolving field of wireless IoT technology.

5. CONCLUSION

This study demonstrates the effectiveness of the 433 MHz LoRa Wireless IoT Technology Trainer as an innovative educational tool for enhancing teaching and learning in wireless communication. By integrating ESP32 boards, LoRa SX1278 modules and adjustable antennas, the trainer successfully bridges the gap between theoretical concepts and practical applications. Hands-on activities enabled students to explore factors affecting signal strength and communication range, including antenna gain, distance, and environmental conditions. The findings highlighted that higher antenna gains significantly improve communication range, with the 12 dBi antenna achieving the longest distance of 405.5 meters, although with diminishing RSSI at extreme distances. Additionally, Line-of-Sight (LOS) scenarios consistently outperformed Non-Line-of-Sight (NLOS) environments, emphasizing the role of environmental factors in wireless communication.

Besides these successes, several challenges were encountered during the implementation of the trainer. Some students found the technical setup of components, such as configuring ESP32 boards and LoRa modules is challenging, which affected their initial engagement. Additionally, a small percentage of students struggled to fully catch the concepts due to limited experience to IoT technologies. Environmental factors, such as interference and obstacles during Non-Line-of-Sight (NLOS) tests, are also one of the practical difficulties that may have hindered consistent learning outcomes.

To address these challenges, several improvements are recommended. Providing comprehensive pre-training materials, including detailed tutorials, videos and step-by-step guides, can help reduce the initial learning curve and ensure that all participants are adequately prepared. Introducing additional support mechanisms, such as one-on-one guidance or small group sessions, can assist students who require more help in understanding IoT concepts. Designing the trainer with more robust and portable components would also make it easier to handle during the outdoor experiments, especially in challenging environments. Furthermore, expanding the scope of practical activities to include real-world applications, such as agriculture or smart city case studies, can further motivate students and demonstrate the relevance of wireless IoT technologies. Finally, optimizing NLOS experiments by developing strategies to mitigate interference, such as using higher-power modules or advanced error correction techniques, could improve learning outcomes in complex scenarios.

In conclusion, the 433 MHz LoRa trainer has proven to be a valuable educational innovation, equipping students with essential technical skills for wireless communication and IoT technologies. With the suggested improvements, it has the potential to further enhance learning outcomes, foster student engagement, and better prepare students for real-world challenges in the rapidly evolving field of wireless communication.

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