



Enhancing STEM Education through IoT-Based Distance Monitoring Projects in High Schools

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Abstract

This community service program was conducted in response to the demands of the Fourth Industrial Revolution, which requires stronger digital literacy and practical STEM competencies in schools. The program aimed to introduce IoT-based STEM learning to teachers and students at Situraja State Senior High School (SMAN Situraja), a rural school in West Java, Indonesia, to enhance digital literacy and promote hands-on STEM education. To achieve this, the program implemented an IoT-based distance monitoring project using an ultrasonic sensor, an ESP32 microcontroller, and the Blynk platform through a project-based learning approach that included lectures, collaborative practical sessions, and interactive feedback activities. The program was evaluated using post-activity questionnaires administered to both teachers and students to capture their perceptions of the learning activities and outcomes. The results showed highly positive teacher responses, with 75–100% of participants selecting "strongly agree across all evaluation items, including 100% agreement on understanding IoT data transmission and the relevance of STEM integration. Student feedback also indicated positive motivation toward STEM learning, with 48% of students strongly agreeing that the activity increased their interest in STEM. However, student responses related to physics concept understanding and real-world application were more varied, with up to 48% selecting neutral responses in these areas. This difference suggests that teachers more readily recognized the instructional relevance of the program, while some students were still adapting to newly introduced IoT and physics concepts.

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INTRODUCTION

Today's digital era is strongly shaped by the Fourth Industrial Revolution, which has transformed the way people learn, work, and compete in a rapidly changing job market. In this context, individuals are expected to develop competencies related to automation, big data analytics, robotics, artificial intelligence (AI), and the Internet of Things (IoT) (OECD, 2023; World Economic

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Forum, 2020). Early exposure to technology at the secondary school level enhances students' adaptability (KORKMAZ et al., 2021), and STEM-based education (Science, Technology, Engineering, and Mathematics) has been widely promoted to prepare learners for these challenges (R. W. Bybee, 2013).

Nevertheless, access to practical and contextual STEM learning remains uneven, especially in non-urban settings. In Indonesia, disparities in digital access are still visible: one study reported that internet access among students in rural areas was 66.87%, compared with 85.13% in urban areas, while access to computers was also substantially lower among disadvantaged groups. In addition, OECD PISA 2022 data show that only 18% of students in Indonesia had access to computer programming classes or activities at school at least once a week, indicating that structured exposure to applied digital-STEM learning is still limited (Bond et al., 2020; Larson & Miller, 2011; Norman et al., 2022).

Low levels of digital literacy among both teachers and students further constrain the effective use of technology in school (Garzón-Artacho et al., 2021; Julian Fraillon et al., 2018). In Indonesia and across Southeast Asia, rural-urban disparities in internet connectivity, device ownership, and school infrastructure remain evident, with household computer ownership and internet access in rural areas consistently lagging behind urban regions (Intimedia, 2024; Katadata, 2024). International monitoring reports also emphasize that unequal access to digital technologies and insufficient teacher preparedness continue to limit the integration of technology-enhanced STEM learning in many developing contexts (UNESCO, 2023). At Situraja State Senior High School (SMAN Situraja) in West Java, a Science Club (Kelompok Ilmiah Remaja/KIR) has already been established to facilitate general student scientific activities. However, prior to this program, the school had not yet conducted structured short-term workshops, regular practical sessions, or longer-term mentoring activities related to emerging fields such as IoT, robotics, and artificial intelligence. As a result, exposure to these topics among both teachers and students remained limited. These conditions point out the critical need for sustained training, curriculum development, and infrastructural support to strengthen digital and STEM literacy in rural secondary schools (Widajati & Mahmudah, 2023).

Universities can play a strategic role in addressing these challenges through technology-based community service initiatives that provide mentoring, training, and practical digital solutions in collaboration with secondary schools (Kayyali, 2024; Penprase, 2018; Widajati & Mahmudah, 2023). International studies consistently show that integrating IoT into STEM instruction, particularly through project-based learning and low-cost sensor platforms, can improve students' engagement, systems thinking, and data literacy (Auliyani et al., 2025; Chen et al., 2020; I. Tsipianitis et al., 2025). However, systematic reviews indicate that most STEM-IoT interventions have been conducted in well-resourced urban settings and emphasize the necessity of sustained, context-sensitive programs in rural and underrepresented schools (Kassab et al., 2020; Mustafa et al., 2024; D. Tsipianitis et al., 2025; Zhang & Huang, 2025). In Indonesia, the implementation of STEM- and IoT-related learning in schools continues to face structural constraints, particularly in relation to digital infrastructure and sustained teacher professional development. According to the OECD, digital resource availability remains a concern in disadvantaged and rural schools in Indonesia, reflecting uneven levels of readiness for digital learning. Moreover, OECD PISA 2022 data indicate that access to computer programming activities at school remains limited, with only 18% of students attending such classes or activities at least once a week. This challenge is compounded by limitations in teacher professional development, as a World Bank review of online teacher training in Indonesia found that most programs were short in duration, with 19 of 25 reviewed programs lasting no more than one month and only a small number including coaching or feedback mechanisms.

This contrast between international evidence and national practice reveals a clear implementation gap. Although STEM-IoT approaches are increasingly supported by global research, many rural Indonesian secondary schools still face limitations in infrastructure, teacher preparedness, curricular alignment, student exposure to applied STEM technologies, and access to scalable instructional or outreach models. At SMAN Situraja, this gap is reflected in the absence of structured IoT learning activities, limited exposure to advanced digital technologies, and the lack of sustained university-school collaboration frameworks. As a result, opportunities to develop practical digital literacy and contextual STEM learning remain limited for both teachers and students.

The present study reports on a community service program that trains teachers and students at SMAN Situraja to develop a simple IoT-based distance-monitoring system using ultrasonic sensors and ESP32 microcontrollers. The program was designed to improve IoT assembly skills, interdisciplinary STEM understanding, student motivation toward STEM learning, and teachers' readiness to integrate IoT-supported instruction. It was implemented through project-based learning, hands-on prototyping, and reflective discussions that linked technological practice with physics concepts and mathematical data analysis. The activity involved approximately 25–30 participants. Program outcomes were evaluated using post-activity questionnaires, rubric-based assessments, and structured reflective feedback instruments.

This initiative supports the Sustainable Development Goals through clearly defined learning activities and outcomes. It contributes to Sustainable Development Goal 4 on quality education by providing teachers and students with hands-on STEM-IoT learning experiences such as IoT assembly, system prototyping, and real-time data monitoring. These activities expanded access to more meaningful, practical, and contextual learning opportunities in a rural school environment. The initiative also contributes to Sustainable Development Goal 9 on industry, innovation, and infrastructure by introducing digital technologies and strengthening participants' technological competence, problem-solving abilities, and awareness of innovation. Through these outcomes, the program helped build a stronger foundation for digital learning and innovation in rural secondary education. The novelty of the program lies in its integration of low-cost IoT technologies, physics-contextualized STEM instruction, and sustained university–school collaboration within a rural community service framework. By positioning teachers and students as co-learners in a single training model and embedding IoT construction within curriculum-relevant science contexts, the program contributes a replicable STEM–IoT-based community service model for secondary schools and offers empirical insights for future initiatives aimed at reducing digital disparities and strengthening innovation-oriented learning ecosystems beyond major urban centers.

This study addresses the implementation gap between the growing international support for STEM-IoT education and the limited availability of structured, practice-oriented digital learning models in rural Indonesian schools. In this context, the program offers a contextual and adaptable approach by integrating low-cost IoT technology, physics-based STEM learning, and project-based activities for teachers and students at SMAN Situraja. The study is expected to provide a replicable community service model for rural secondary schools while also offering empirical insights into how university-school collaboration can support digital literacy and innovation-oriented learning.

METHOD

Target Community

This community service program was implemented at Situraja State Senior High School (SMAN Situraja), located in Situraja District, Sumedang Regency, West Java Province. SMAN Situraja is a state senior high school established in 1976 and has an A accreditation from the National Accreditation Board for Schools/Madrasahs (BAN-S/M), demonstrating the school's commitment to superior quality education.

This school is not in a big city center; its location in a non-urban area makes it an ideal location for a community service-based program that aims to reduce the digital divide and increase access to technology education as a medium for STEM learning. This school's location shows the importance of providing inclusive educational support and ensuring that students in all areas can learn about modern learning technologies such as the Internet of Things (IoT). This condition makes the training program have a greater impact, especially in encouraging equal access to STEM-based education.

This activity was attended by around 26 participants, consisting of students in grades 10th and 11th and teachers who are interested in developing project-based learning methods using real and affordable technology. Participants who participated were interested in technology and were ready to join in direct practical learning. Most students had a basic understanding of computers but had never used a microcontroller or IoT system. The teachers welcomed this activity because it provided new insights into integrating technology into science learning in a contextual and fun way.

Proposed Method

The proposed implementation method for community service activities is through a workshop on making Internet of Things (IoT)-based projects as a STEM learning medium to understand simple science concepts such as ultrasonics. IoT-based as a STEM learning medium has proven effective in helping Improve Student Learning Outcomes (Amador Nelke et al., 2024; Fuadi et al., 2022; Hamid et al., 2022; Istiqomah et al., 2023; Qolbiyah et al., 2025; Terzieva et al., 2025). By involving participants in the design, assembly, programming, and testing of IoT-based distance monitoring tools, students can experience firsthand the learning cycle starting from problem identification, solution design, data collection, data analysis, to evaluation of results (Prihatiningrum et al., 2022; Ristianti et al., 2024). This project-based approach aims to integrate understanding of science, technology, engineering, and mathematics concepts into real activities that are contextual and applicable. The flow of this activity can be explained through the following chart in Figure 1.

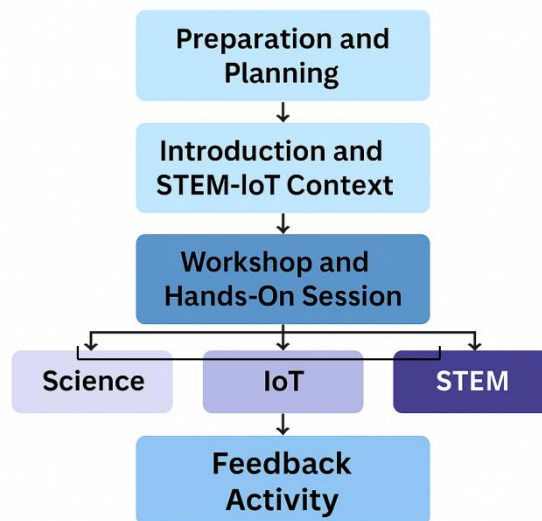


Figure 1. Proposed Method

Figure 1 is a picture of the overall flowchart of this community service activity. The activities flow starts from the Preparation and Planning stage to develop concepts and adjust the activity needs at Situraja State Senior High School. Moreover, the training event begins with an Introduction and STEM-IoT Context to provide an initial understanding of IoT's application in the STEM context, such as understanding the ultrasonic sensor science concept, microcontrollers, and IoT. Furthermore, participants take part in the Workshop and Hands-On Session in the form of direct practice in building or programming IoT-based devices. After that, participants are directed to explore learning outcomes through the Science, IoT, and STEM paths to understand the integration of theory and real applications. The activity ends with a feedback activity, which is an evaluation and reflection to improve the program's quality in the future.

Preparing and Planning

The Preparation and Planning stage is a crucial initial step that must be carefully organized in the implementation of this community service activity. At this stage, the implementation team, consisting of lecturers and students, conducts an assessment of the needs and characteristics of the participants, namely students and teachers at Situraja State Senior High School. Additionally, the school's facilities, such as the availability of computers and internet access, are also evaluated at this point, as these are essential supporting resources for the smooth execution of the program. The training materials and learning tools are adjusted based on initial coordination with the school and a review of relevant STEM curricula. The purpose of this adjustment is to ensure that the designed activities can effectively bridge students' understanding of basic science concepts, such as ultrasonic sensors, through a project-based IoT approach. Moreover, the team develops strategies to integrate STEM-based learning into the training effectively.

This stage also includes technical planning, which covers scheduling the activities, preparing training modules, hardware components such as microcontrollers and sensors, as well as supporting software. The team prepares a comprehensive training module containing step-by-step instructions for installing the necessary tools on laptops, operating the devices, and using evaluation instruments throughout the program. One of the key components introduced in the training is an IoT-based system for distance monitoring using an ultrasonic sensor and an ESP32 microcontroller. The ultrasonic sensor was chosen because it effectively demonstrates the real-world application of physics concepts, particularly ultrasonic waves. It provides a practical example of how classroom theory connects to modern technology. The microcontroller, in this case the ESP32, serves as the core component of the IoT system, enabling data processing and communication. As illustrated in Figure 2, the system block diagram shows the integration flow starting from the ultrasonic sensor as the data acquisition unit, followed by data processing and transmission by the ESP32 microcontroller, and ending with real-time data visualization through the Blynk cloud platform.

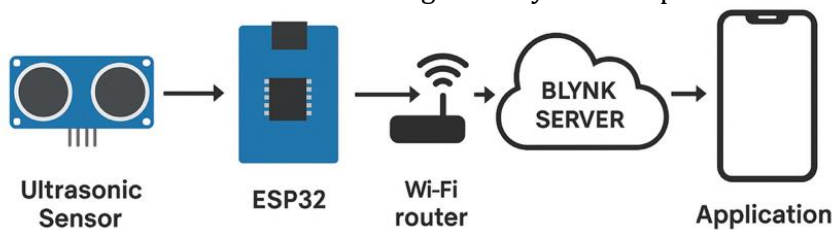


Figure 2. IoT System for Training

This system architecture then became the main learning framework used in the workshop, serving as a reference for participants to explore the integration of physics concepts, programming, and IoT system implementation through hands-on activities. In this workflow, the ultrasonic sensor first detects the distance of an object, and the data is sent to the ESP32, which functions as the main processing unit. The ESP32 then transmits this data wirelessly through a Wi-Fi router, in this case, using mobile phone tethering, to the Blynk server which is as a cloud-based platform that facilitates real-time data communication. Finally, the data is displayed through a mobile application connected to the Blynk server, allowing users to monitor the sensor readings in real time. Through this implementation, the system provides a concrete and hands-on demonstration of how science and technology can be integrated into real-world applications, thereby enhancing participants' understanding of STEM concepts in a practical, contextual, and interactive manner.

Introduction and STEM-IoT Context

The workshop began with an introduction to IoT for participants, consisting of students and teachers who may have never known the technology. Then, describe the IoT architecture and components in the IoT system. The next stage is to give examples of IoT systems in everyday life, such as smartwatches, online motorcycle taxi applications, or smart refrigerators. The next stage, after introducing the IoT system and architecture, is the workshop's explanation of the IoT system that will be created, starting with introducing sensors, microcontrollers, networks to be built, and applications to be created. Then, the emphasis of implementing the system is given to how the STEM concept (Science, Technology, Engineering, and Mathematics) is integrated into an IoT-based system, which offers a multidisciplinary learning experience for students and teachers.

Workshop Structure and Hands-on Session

In stages, participants are guided through assembling a simple IoT-based distance monitoring system using an ultrasonic sensor (HC-SR04) and ESP32. This session includes:

Programming Ultrasonic Sensors with Microcontrollers

This stage begins with an introduction to the concept of ultrasonic sensors as sensors for detecting object distances, including an explanation of the physics theory used, such as the principle of ultrasonic waves and time-of-flight measurements. This concept is then linked to its implementation in microcontroller programming. Next, the hands-on training session begins with an introduction to microcontrollers, especially ESP32, and how to wire a microcontroller to an

ultrasonic sensor. After that, there is an introduction to microcontroller programming, including an explanation of the program structure and steps in programming an ultrasonic sensor to read and send distance measurement data in real time.

Device Integration into IoT System

This stage of the workshop is structured to assist participants in incorporating data acquisition devices into IoT systems by utilizing ultrasonic sensors and ESP32 microcontrollers. The integration process is implemented through a series of organized and sequential steps. First, participants are introduced to the Blynk platform as a middleware that bridges the connection between ESP32 devices and user interface applications on mobile devices. At this stage, participants understand the role of Blynk in IoT systems and how to configure it.

Next, participants learn ESP32 programming to send data from ultrasonic sensors to Blynk via Wi-Fi. The focus of the training is on compiling code using the Arduino IDE, integrating the Blynk library, and understanding the program workflow so that data can be sent and displayed in real-time. Afterward, participants are directed to create a visual interface in the Blynk White App by adding elements such as Value Display and Graph to visualize sensor data.

Feedback Activity

To evaluate the effectiveness of this community service activity, a quantitative evaluation approach was conducted using a post-activity survey distributed to all participants ($n = 26$), consisting of high school students (grades 10 and 11) and teachers. The survey was administered after participants completed the entire series of workshops, as presented in Table 1. The instrument was designed using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). This survey aims to measure the extent to which the IoT-based training contributes to improving participants' understanding of science concepts (particularly physics), technology utilization, and the integration of STEM-based learning (Science, Technology, Engineering, and Mathematics). The survey statements cover several aspects, including understanding of ultrasonic sensors, comprehension of IoT systems and data transmission, interest in technology, critical thinking skills, and the ability to apply scientific concepts in real-life contexts.

The respondents consisted of students with basic computer literacy but limited experience with microcontrollers and IoT systems, as well as teachers interested in integrating technology into STEM learning. The survey statements, as shown in Table 1, were developed to evaluate several key aspects, including: (1) understanding of science concepts (particularly physics related to ultrasonic sensors), (2) understanding of IoT systems and data transmission, (3) relevance to STEM learning, (4) interest and motivation toward technology, (5) ability to apply knowledge in real-life contexts, and (6) improvement in critical thinking skills.

The collected data were analyzed using descriptive statistical methods, including percentage distribution and mean score analysis for each statement. The mean score was used to determine the overall level of agreement among participants. The success of the program was determined based on the following indicators: high average scores (≥ 4.0) indicating positive participant responses, increased understanding of IoT and science concepts, increased interest and motivation in STEM learning, and positive perception of the applicability of IoT-based learning in real-life contexts. This evaluation approach provides a structured and measurable way to assess the impact of the IoT-based STEM training program.

Table 1. Feedback Statements for Participant

No	Statements
1	This training improved my understanding of science (physics) concepts.
2	I understood how ultrasonic sensors work after the training.
3	I understood how data is transmitted through the IoT system.
4	This training is relevant to STEM concepts (Science, Technology, Engineering, Mathematics).
5	I feel more interested in learning about technologies such as IoT.
6	I can apply this knowledge in real-life or school contexts.
7	This activity motivated me to learn more about STEM.
8	I feel this activity improved my critical thinking skills.

RESULTS AND DISCUSSION

This section reports the outcomes of the community service workshop and discusses the findings in relation to STEM-based IoT learning. The presentation begins with a description of the workshop implementation, followed by the survey results obtained from teachers and students, and concludes with a discussion of the key findings and their implications for STEM education.

Workshop Implementation

The workshop was conducted through interactive face-to-face training combining theoretical explanation and hands-on practice. Participants were divided into small groups of three, each guided by an assistant to ensure effective learning and technical support, as shown in Figure 3. This structure facilitated active participation and enabled participants to directly experience the process of assembling, programming, and testing IoT-based systems in a STEM learning context.



Figure 3. The conduct of the IoT system group training session

Result Evaluation

To evaluate the effectiveness of the training from multiple perspectives, a post-activity survey was administered to both teachers and students as representatives of different subject groups involved in the program. Teachers' responses reflect instructional and pedagogical viewpoints, while students' responses capture learning experiences, conceptual understanding, and motivational aspects. The survey results are presented separately to provide a comprehensive overview of how the IoT-based STEM training was perceived by each group.

The following results present teachers' survey responses, as shown in Figure 4, which represent educators' perspectives on the effectiveness and relevance of the IoT-based STEM training. The survey results show that most teachers responded very positively, with 75% to 100% selecting strongly agree for each statement. Notably, Q3 (understanding how data is transmitted through the IoT system) and Q4 (relevance of the training to STEM concepts) both received 100% strongly agree, indicating that the training content was highly relevant and effective in demonstrating the application of technology in education. Other items, such as understanding physics concepts, sensor functionality, motivation, and critical thinking, also received consistently high agreement, with 75% strongly agree and 25% agree and no neutral or negative responses.

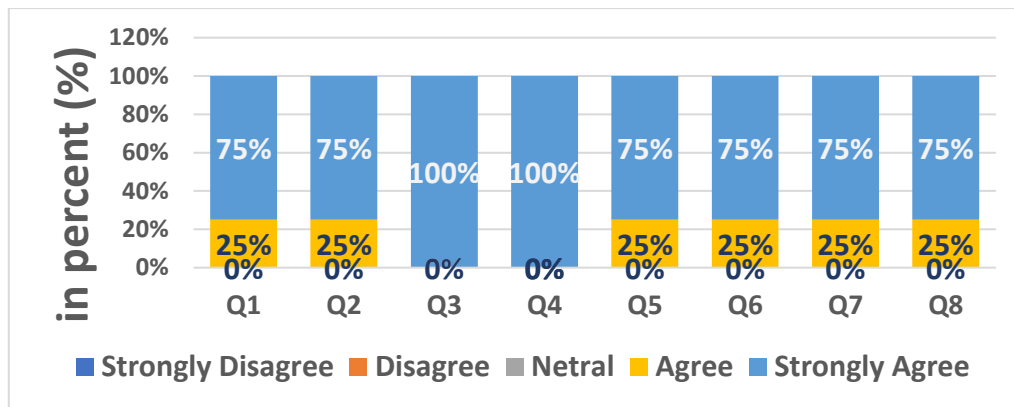


Figure 4. Feedback Result of the Teacher

According to the teacher, this training has greatly improved our comprehension of theoretical ideas and technical abilities, especially when it comes to using physics and IoT in practical learning situations. Additionally, it has increased interest and drive to investigate and apply STEM-based teaching methods in our classrooms. Because of the combination of in-depth explanations, practical hands-on exercises, and tight supervision, the training was both enlightening and highly relevant to our role as instructors. Because of the training, we are now more confident and capable of integrating STEM ideas and technology into our teaching methods.

Based on the survey results shown in Figure 5, student responses to IoT training showed diversity in their understanding and perception. Several aspects, such as Q2 (understanding how ultrasonic sensors work) and Q4 (relevance of training to STEM concepts), received very positive responses, with the majority of students choosing strongly agree (62% and 43%). However, for Q1 (understanding science/physics concepts) and Q6 (application of science in real contexts), many students chose neutral (48% and 43%, respectively), and a small number even expressed disagreement in Q5 and Q6. However, quite encouraging results emerged in Q7 and Q8, where 48% of students strongly agreed that this activity motivated them to learn more about STEM and improve their critical thinking skills.

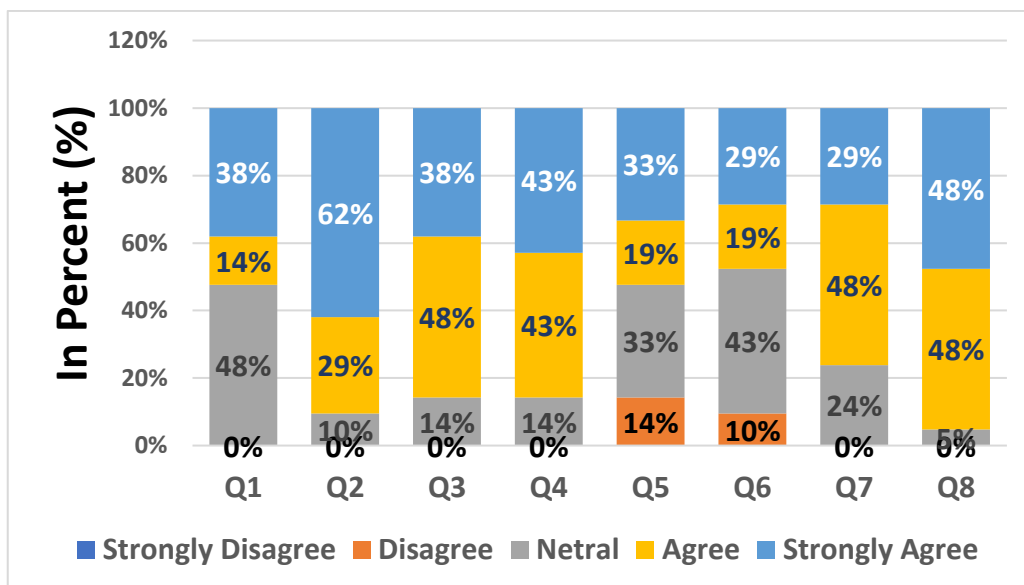


Figure 5. Feedback Result of the Student

These findings indicate that students experienced the IoT-based training differently across learning aspects. While the activity was effective in stimulating motivation and critical thinking skills, as reflected in the high agreement levels in Q7 and Q8, students' conceptual understanding of fundamental physics principles and their application in real-world contexts remained varied. This suggests that although the hands-on IoT approach successfully engaged students and increased their

interest in STEM, additional instructional support is needed to strengthen conceptual comprehension, particularly for learners with limited prior exposure to technical materials.

Based on the comparative results presented in Table 1, a clear contrast is observed between teacher and student perceptions of the IoT-based STEM training. Teachers consistently reported higher levels of strongly agree across all evaluated aspects, indicating a strong understanding of both conceptual and system-level components of the training. In particular, aspects related to IoT system architecture and STEM relevance (Q3 and Q4) achieved the highest agreement among teachers, reflecting their ability to grasp the integration of technology and pedagogy within the training framework.

In contrast, student responses showed greater variability, especially in aspects related to conceptual understanding and real-world application. Lower levels of strongly agree were observed for understanding physics concepts (Q1) and applying science in real contexts (Q6), suggesting that foundational scientific concepts remain challenging for students. However, relatively higher agreement levels were found for understanding ultrasonic sensor operation (Q2) and critical thinking development (Q8), indicating that hands-on activities effectively supported practical understanding and higher-order thinking skills.

Interestingly, the gap between teachers and students narrowed in motivational and affective aspects. While teachers still reported higher motivation levels (Q5), students demonstrated notable interest and engagement in STEM learning, particularly in critical thinking development (Q8). These findings suggest that although students may require additional instructional support to strengthen conceptual mastery, IoT-based project learning is effective in fostering engagement, motivation, and critical thinking skills. Overall, this comparison highlights the complementary perspectives of teachers and students and underscores the importance of contextual and scaffolded instruction to bridge conceptual gaps in STEM learning.

Table 1. Comparison of Teacher and Student Survey Results

Question	Aspect Evaluated	Teacher: Strongly Agree (%)	Student: Strongly Agree (%)	Key Difference
Q1	Understanding physics concepts	75	38	Students show lower conceptual understanding
Q2	Understanding ultrasonic sensors	75	62	Students understand device operation well
Q3	IoT data transmission	100	38	Teachers grasp system architecture better
Q4	Relevance to STEM concepts	100	43	Teachers perceive stronger STEM alignment
Q5	Motivation to learn STEM	75	33	Motivation higher among teachers
Q6	Applying science in real context	75	29	Students struggle with real-world application
Q7	Interest in STEM learning	75	29	Student interest present but less consistent
Q8	Critical thinking development	75	48	Strong impact on student higher-order thinking

Discussion

Program of community service demonstrates that project-based IoT STEM training can be effectively implemented in a rural secondary school context through structured, hands-on activities. The systematic sequence, from introducing ultrasonic and IoT fundamentals, ESP32 programming, to cloud-based system integration, enabled participants to experience direct connections between scientific concepts and real-world technological applications. The use of guided group practice aligns with established project-based learning principles, which emphasize experiential learning to integrate science, technology, engineering, and mathematics in a meaningful context.

The findings indicate that the program had a stronger instructional impact on teachers than on students. Teachers perceived substantial improvements in pedagogical readiness and understanding of STEM-IoT integration, suggesting that hands-on system development effectively supports instructional confidence (Moreira et al., 2024). This outcome is consistent with prior studies showing that educators benefit significantly from applied IoT training when it is embedded within structured learning frameworks (Nelke & Winokur, 2020). In contrast, student outcomes showed high motivation and critical thinking development but more varied conceptual understanding, particularly in fundamental physics and real-world application. Such patterns are commonly reported in project-based STEM learning, where engagement and higher-order skills often precede deep conceptual mastery (Chen et al., 2021; Sung et al., 2023).

Table 2. Comparison of IoT-Based STEM Learning Approaches and Outcomes Across Studies

Study	Target Participants	Learning Approach	Main Outcomes	Identified Challenges	Contribution Relative to This Study
(Nelke & Winokur, 2020)	Higher education (curriculum context)	Integrating IoT topics into existing curriculum	Feasible integration of IoT content into teaching	Needs curriculum alignment and instructional adaptation	This study translates IoT integration into a rural high school community-service setting
(Amador Nelke et al., 2024)	STEM learners	IoT learning supported by remote lab	Supports access to IoT practice and learning activities	Requires appropriate learning design and support	This study provides fully hands-on onsite implementation using low-cost ESP32 + sensor + mobile platform
(Chen et al., 2021)	Engineering/STEM learners (review)	Project-Based Learning (PBL)	PBL supports active learning and applied skills	Common challenges: guidance/scaffolding, uneven conceptual depth	Explains why students may show high engagement but variable conceptual understanding
(Sung et al., 2023)	School learners	Classroom STEAM using robotic kits	Positive short-term learning/engagement effects	Learning gains depend on structure and support	Aligns with your finding: motivation & critical thinking improve strongly through hands-on activity
(D. Tsipianitis et al., 2025)	Secondary education (reviewed studies)	Systematic review of IoT in learning	Highlights benefits/affordances of IoT for learning	Notes gaps/constraints in implementation and evidence	Positions your work as an evidence-based rural deployment model with teacher-student survey outcomes
This study	Teachers & students	Project-based IoT STEM training (ESP32 + ultrasonic + Blynk)	High teacher readiness; increased student motivation & critical thinking	Student conceptual understanding varies	Replicable model for underserved schools

A comparison with previous studies, summarized in Table 2, positions this program within the broader landscape of IoT-based STEM education. Unlike curriculum-level or remote-laboratory approaches (Amador Nelke et al., 2024; Nelke & Winokur, 2020). This study emphasizes a fully onsite, low-cost, and community-oriented implementation suitable for underserved schools. Furthermore, the observed variation in student conceptual understanding reflects challenges highlighted in systematic reviews of IoT in education, which stress the importance of instructional scaffolding and contextual explanation (D. Tsipianitis et al., 2025).

Overall, this study contributes empirical evidence that project-based IoT training can enhance teacher readiness and foster student motivation and critical thinking in rural educational settings. The findings suggest that future implementations should incorporate stronger conceptual scaffolding

to balance engagement with understanding, thereby strengthening the long-term impact and scalability of IoT-based STEM community service programs.

CONCLUSION

This community service program addressed limited access to technology-integrated STEM learning in rural schools through a project-based IoT training program at SMAN Situraja. The results showed strong positive teacher feedback, with 75–100% selecting strongly agree across all indicators, including full agreement on IoT data transmission and STEM relevance, reflecting improved instructional readiness and conceptual understanding. Student responses indicated increased engagement, motivation, and critical thinking development, with 48% strongly agreeing that the activity encouraged further STEM learning; however, their understanding of fundamental physics concepts and real-world applications remained varied, with up to 48% reporting neutral perceptions. Overall, the program effectively enhanced digital literacy and STEM learning while highlighting the need for stronger conceptual support. This study contributes a practical and scalable IoT-based STEM training model for rural schools, supporting efforts to reduce the digital divide and expand access to technology-driven education.

AUTHORS CONTRIBUTIONS

II conceived and designed the program, supervised the project, and reviewed the manuscript. KA coordinated the implementation of the activities and managed communication with the partner school. PP contributed to the implementation of the program and supported the preparation of learning materials. TP contributed to the implementation of the project and supported technical activities during the program. NKCS assisted in organizing participants and documenting the activities. JFT designed the evaluation instruments and conducted data collection. TPK analyzed the data and interpreted the results. GN contributed to the literature review.

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