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# Enhancing STEM Literacy and Interest through an Internet of Things (IoT) Workshop for Senior High School Students at SMAN 24 Bandung

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## Abstract

*This community service program aims to enhance students' technological literacy and interest in Science, Technology, Engineering, and Mathematics (STEM) through an Internet of Things (IoT) workshop conducted at SMAN 24 Bandung. The program adopted a project-based and hands-on learning approach, implemented through three stages: preparation, workshop implementation, and evaluation. The workshop was delivered in four sessions, covering fundamental IoT concepts, programming of the ESP12 (ESP8266-based) microcontroller using Arduino IDE and Node-RED, and sensor data integration with cloud platforms. Program effectiveness was evaluated using pre-test and post-test assessments as well as final project evaluation. The results demonstrate a significant improvement in students' learning outcomes, with an average increase of 8.34 points between pre-test and post-test scores, and most participants achieving maximum scores in the final project assessment. In addition to cognitive gains, students exhibited high engagement and improved problem-solving skills through the development of simple IoT prototypes. Overall, this program successfully strengthened students' understanding of IoT concepts and provided learning modules and equipment that support the school's capacity to implement the Merdeka Curriculum. In addition to improving students' learning outcomes, the program provided social and educational benefits for participating students. The workshop encouraged active participation, teamwork, and greater confidence in using IoT technologies. It also increased students' interest in STEM-related topics through direct experience in developing simple IoT applications. Furthermore, the provision of reusable IoT starter kits and learning modules supports the continued implementation of practical learning activities at SMAN 24 Bandung.*

***Keywords***: *high-school education, internet of things, project-based learning, STEM, technological literacy*

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## Introduction

The rapid development of the Industrial Revolution 4.0 has transformed the competency requirements of human resources, prompting the education sector to ensure that students possess technological literacy, digital literacy, and critical thinking skills grounded in science, technology, engineering, and mathematics (STEM). The internet of things (IoT) is one of the emerging technologies with significant potential to enhance learning quality and improve the efficiency of school management (Arpan et al., 2024). Therefore, developing an understanding of IoT concepts at the secondary school level is essential as a foundational step in preparing students to adapt to future technological advancements.

The implementation of the Merdeka Curriculum promotes flexible learning through project-based activities and the exploration of digital technologies. However, schools' readiness in terms of infrastructure, instructional materials, and human resources remains a significant challenge. SMAN 24 Bandung has introduced the internet of things (IoT) as part of its instructional content; nevertheless, its implementation faces several limitations, particularly the insufficient number of Informatics teachers and the lack of adequate IoT learning facilities. Consequently, IoT instruction is primarily delivered at an introductory level, resulting in limited opportunities for students to engage in practical and applied learning. As a result, students' understanding of IoT concepts remains largely theoretical and insufficiently developed in terms of real-world application.

Several community service studies have demonstrated that interactive workshop-based and hands-on learning approaches are more effective than purely theoretical instruction. Arpan et al. (2024) reported that IoT training conducted at SMA Negeri 2 Binjai not only enriched teaching methods and increased student engagement but also facilitated real-time and efficient school facility management. Other studies have concluded that robotics and IoT workshops significantly enhance students' curiosity, self-confidence, and creativity in addressing technology-related problems (Putra, 2023; Sari, 2024).

The community engagement activities conducted by Mege et al. (2025) through IoT training for senior high school students in Lampung demonstrate that hands-on practice significantly enhances students' understanding of IoT systems, as evidenced by the improvement from a pre-test score of 40% to a post-test score of 80%. Fahlevi et al. (2025) further reported that

project-based workshops increased students' comprehension to 86.7%, indicating their effectiveness in transferring fundamental knowledge and skills. Beyond IoT technology, the integration of electrical engineering practices within STEM activities has been shown to enhance students' technical competencies and computational thinking skills in solving practical problems (Siswoyo et al., 2025).

In line with these findings, this community service program was designed to:

1. Provide practice-based IoT learning experiences for students of SMAN 24 Bandung.
2. Support the school in providing instructional resources in the form of IoT kits that can be used sustainably.
3. Develop an IoT syllabus and learning modules that can be implemented by informatics teachers as elective course materials.

Through the implementation of a structured IoT workshop, students are expected not only to gain a solid understanding of IoT concepts but also to develop simple IoT prototypes using ESP12 microcontrollers, sensors, and cloud platforms. This approach is anticipated to enhance students' interest in STEM and to create opportunities for their involvement in technology competitions or applied research at the secondary school level.

## Methods

This community service program (*PKM*) employed a workshop-based approach grounded in project-based learning (PjBL) and hands-on learning, in accordance with best practices in STEM and IoT education. The methodology comprised three main stages: preparation, workshop implementation, and evaluation/monitoring. The program was conducted over a one-month period at SMAN 24 Bandung (August–September 2025).

Figure 1 presents the coordination meeting held with SMAN 24 Bandung prior to the implementation of the workshop. During the meeting, both parties discussed the workshop agenda, participant selection, learning materials, and technical preparations. The discussion helped align the planned activities with the school schedule and the learning needs of the participating students.

Fig. 1. Coordination activities on learning materials with the partner institution

SMAN 24 Bandung played an active role in the implementation of this program. Teachers collaborated with the project team to identify learning needs, determine participant eligibility, and ensure alignment between the workshop content and the Merdeka Curriculum. They also supported classroom activities by facilitating discussions and supervising student engagement throughout the training sessions. After the workshop, teachers participated in the evaluation process by providing feedback on student learning outcomes and identifying opportunities for the continued use of IoT materials in school-based learning. Such involvement reflects a collaborative partnership model that supports both program effectiveness and sustainability.

Subsequently, an IoT syllabus and learning modules were developed, referring to the STEM–PjBL model that has been demonstrated to be effective for secondary school education. In addition, IoT equipment was procured in the form of 12 starter kits, each consisting of an ESP12 device, various sensors, a breadboard, and jumper wires to be used by student groups. Figure 2 presents the starter kits utilized in this community service program.

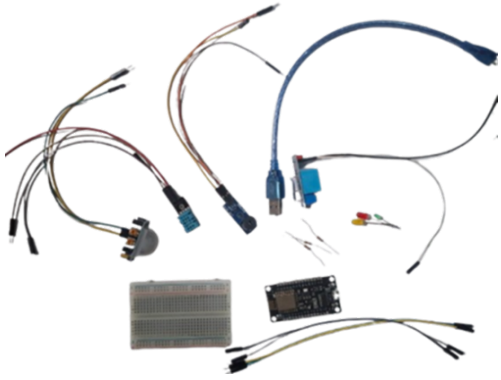

Fig. 2. Internet of things (IoT) starter kit

Upon finalizing the learning modules and preparing the IoT starter kits, internal training sessions were conducted for all undergraduate students who supported the implementation of the community service program. This training aimed to ensure a shared understanding of the instructional materials, technical procedures, and workshop delivery mechanisms.

The second phase involved the implementation of the IoT workshop, which was conducted over a four-week period, with each session lasting 120 minutes. The workshop was structured to progressively introduce IoT concepts and hands-on activities. Table 1 presents a detailed overview of the instructional topics delivered throughout the program.

Table 1. Community service program activities

| Week | Learning Materials | Student Activities | Expected Outcomes |
|---|---|---|---|
| 1 | IoT concepts, applications, and components | Presentations and discussions | Initial understanding of IoT concepts and components |
| 2 | ESP12 programming | Coding and program debugging using Arduino IDE | Understanding of application usage |
| 3 | Node-RED programming | Coding and program debugging using Node-RED | Understanding of application usage |
| 4 | Sensor data integration to the cloud | Transmitting sensor data to the cloud and real-time dashboard monitoring | IoT prototype development |

The final stage involved evaluation and monitoring, employing pre-test and post-test instruments to assess improvements in students' understanding of IoT concepts and their technical skills. The pre-test and post-test results were subsequently analyzed, and the findings were used to formulate recommendations for the sustainability of the community service program. This evaluation approach was aligned with the project-based learning (PjBL) model, which has been shown to have a significant impact on students' 21st-century skills (Sappaile et al., 2024). In addition to evaluating learning outcomes, the school was provided with instructional modules and IoT starter kits. This sustainability-oriented approach refers to the IoT learning ecosystem framework for secondary education (Benita et al., 2021).

## Results and Discussions

The community service program in the form of an IoT workshop at SMAN 24 Bandung demonstrated a tangible impact on improving students' knowledge, practical skills, and interest

in STEM. The workshop was conducted over four sessions with a total of 36 participants consisting of Grade XII students from the informatics specialization. Figure 3 shows the scene of the workshop implementation.

Fig. 3. Community service program activities

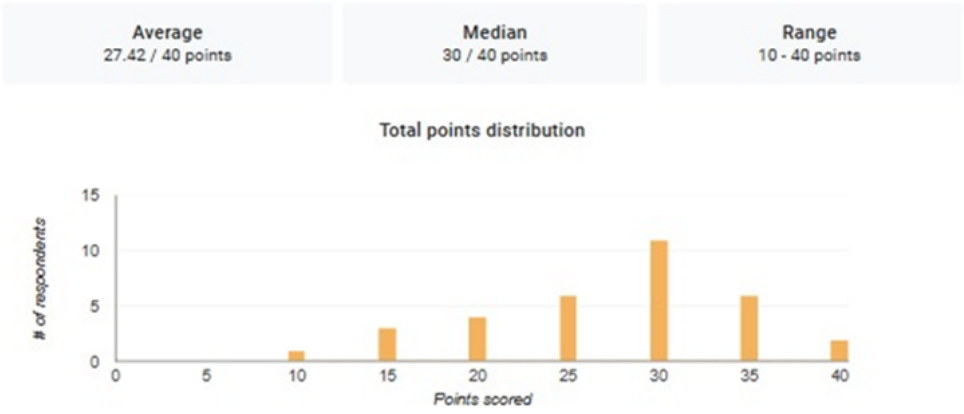


Fig. 4. Pre-test results from the first session

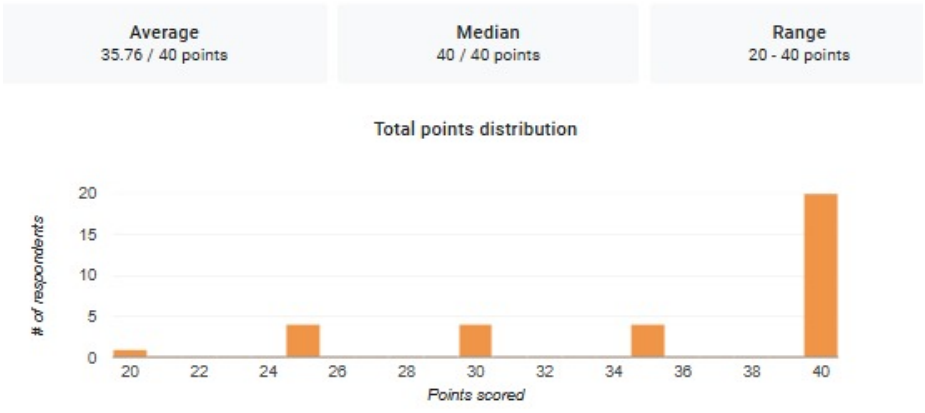


Fig. 5. Post-test results from the first session

The evaluation of participants' cognitive abilities was conducted through pre-test and post-test assessments during the first session, focusing on the introduction of IoT concepts, the functions of sensors and microcontrollers, and an understanding of cloud platforms. Figures 4 and Figure 5 present the pre-test and post-test results.

The evaluation results from the first session indicate a clear improvement in students' understanding of IoT concepts. The mean score increased by 8.34 points, while the median score increased by 10 points, reflecting better overall comprehension after the workshop. The minimum score also improved from 10 to 20 points, suggesting that students with limited prior knowledge were able to benefit from the learning activities. Furthermore, the post-test distribution was dominated by the maximum score of 40 points, achieved by nearly 20 participants. This pattern indicates that the workshop not only improved average performance but also helped many students reach a higher level of understanding. These improvements may be attributed to the hands-on learning approach, which allowed students to directly observe how sensor data were collected and displayed through cloud-based applications.

During sessions 2 to 4, hands-on practical activities were conducted, in which students worked collaboratively in groups of three. Each group engaged in the following learning activities:

a. Wiring the ESP12 with various sensors.
b. Programming the ESP12 using the Arduino IDE.
c. Developing IoT applications using Node-RED.
d. Integrating all components into a functional IoT system.

The evaluation results of these activities are presented in Figures 6, Figure 7, and Figure 8.

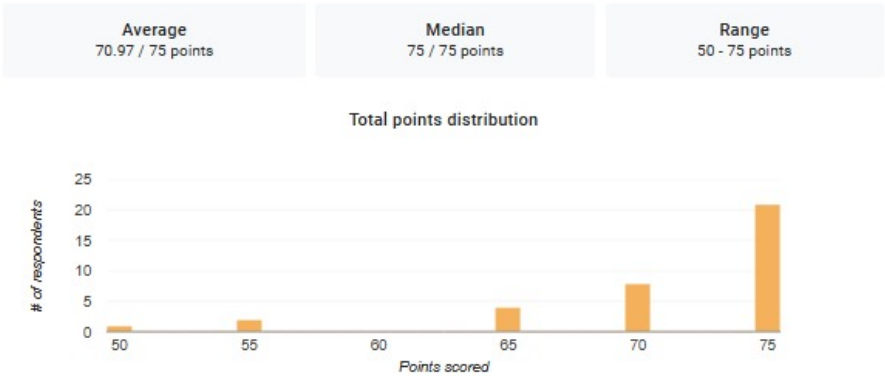


Fig. 6. Questionnaire results on the introduction to Arduino IDE programming

The questionnaire results for the Arduino IDE programming session showed a high level of participant understanding, with an average score of 70.97 out of 75 points. Approximately 21 students achieved the maximum score of 75, indicating that most participants were able to follow the programming activities successfully. These results suggest that the use of Arduino IDE was appropriate for introducing basic programming concepts in an IoT learning environment. Through direct practice, students were able to write simple programs, upload code to the microcontroller, and observe the interaction between software and hardware components.

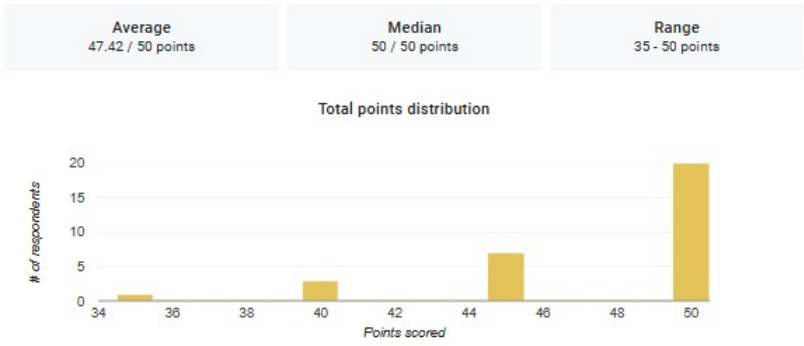


Fig. 7. Questionnaire results on the introduction to the Node-RED application

This questionnaire yielded an average score of 47.42 out of 50 points, indicating that participants had achieved a very high level of mastery of the Node-RED material. The consistently high scores obtained in the Node-RED session indicate that students were able to understand visual programming concepts and data-flow logic effectively. Compared with traditional text-based programming environments, Node-RED offers a more intuitive interface that allows learners to focus on system integration and IoT communication principles. This outcome demonstrates the potential of low-code development platforms to support STEM learning among beginners. The results of the final questionnaire related to IoT application learning are presented in Figure 8.

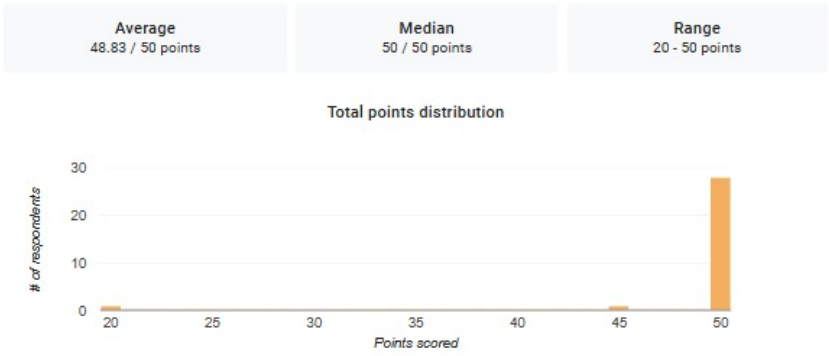


Fig. 8. Questionnaire results on IoT application

The final project results demonstrate a very high level of students' mastery of practical applications. An average score of 48.83 out of 50 points indicates that the training successfully achieved its intended application mastery objectives. Nearly all respondents (approximately 29 students) attained a perfect score of 50 points, serving as a strong indicator that participants were able to effectively integrate and apply all training components; sensors, microcontrollers, programming, and Node-RED, within the final project. These findings are consistent with those reported by Bunyamin, who identified project-based learning as an effective alternative instructional model for enhancing student engagement and learning outcomes (Bunyamin, 2023). This result also aligns with Tsipianitis et al. (2025), who reported that IoT integration has a positive impact on student learning and strengthens STEM competencies.

From an economic perspective, the IoT kits and learning modules provided through this program can be reused in future learning activities. As a result, the school can continue implementing similar practical sessions without requiring significant additional resources. This supports the sustainability of IoT-based learning while reducing the need for repeated procurement of instructional materials.

Overall, the workshop produced positive outcomes for both students and the partner school. In addition to improving students' understanding of IoT concepts and basic programming skills, the activities encouraged active participation and teamwork during the practical sessions. The availability of learning modules and IoT kits also provides opportunities for the school to continue similar activities in future informatics classes and extracurricular programs.

## Conclusion

The community service program in the form of an internet of things (IoT) workshop conducted at SMAN 24 Bandung successfully improved students' conceptual understanding, practical competencies, and interest in STEM through a project-based and hands-on learning approach. Evaluation results demonstrated measurable learning gains, reflected by an average increase of 8.34 points between pre-test and post-test scores, while most participants achieved near-maximum scores in the final project assessment. The program also successfully achieved its objectives of enhancing IoT literacy, providing sustainable learning resources through IoT starter kits, and developing instructional modules and syllabus materials for future implementation.

In addition to improving students' learning outcomes, the program contributed to broader social and economic impacts. Socially, students demonstrated increased engagement, collaboration, technological confidence, and interest in STEM-related activities. Economically, the provision of reusable IoT starter kits, instructional modules, and syllabus materials strengthened the school's instructional capacity and supported the sustainable implementation of IoT-based learning.

The active involvement of the partner institution throughout preparation, implementation, and evaluation stages contributed significantly to program effectiveness. As a continuation strategy, the developed modules and IoT kits are expected to be integrated into future Informatics learning activities and extracurricular programs at SMAN 24 Bandung. Further implementation may involve teacher capacity-building and expansion toward wider STEM-based educational initiatives.

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and support of all stakeholders, this program would not have been successfully implemented or achieved its positive impact on enhancing technological literacy within the school community.

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