

*Original Paper*

## Smart Learning for Sustainable Futures: Implementing an IoT-Based Light Detection Project Using Micro:bit Secondary Education

Dhianti Mei Rahmawantary<sup>1</sup>, Yuaniko Paramitra<sup>2\*</sup>, Pretty Failasufa Aziza<sup>3</sup>, Retno Dwi Rahayu<sup>4</sup>, Salwa Salsabila Firdaus<sup>5</sup>

<sup>1,2,3</sup> Lecturer, Universitas Krisnadwipayana, Jakarta

<sup>4,5</sup> Universitas Krisnadwipayana, Jakarta

Corresponding author: Yuaniko Paramitra ([nicoyp@unkris.ac.id](mailto:nicoyp@unkris.ac.id))

Received: 03-05-2026; Accepted: 25-05-2026

### Abstract

This community service program aimed to enhance digital literacy, technological understanding, and sustainability awareness among secondary school students through an IoT-based light detection project using BBC Micro:bit. The program addressed students' limited exposure to practical Internet of Things applications and energy-efficient technologies in school learning environments. A Project-Based Learning (PjBL) approach was applied through interactive workshops involving IoT concepts, sensor technology, and block-based programming using the MakeCode platform. Participants designed and tested a light-detection system capable of automatically responding to environmental lighting conditions. Program evaluation was conducted using observations, practical assessments, questionnaires, and reflective discussions to measure participants' understanding, technological skills, and learning engagement. The findings indicated improvements in students' understanding of IoT concepts, programming logic, sensor applications, and awareness of energy efficiency practices. Participants also demonstrated increased confidence, collaboration, and problem-solving abilities during practical activities. In addition, teachers gained insights into integrating technology-based and sustainability-oriented learning into classroom instruction. The program highlights the potential of experiential IoT learning to support STEM education, strengthen digital competencies, and promote environmentally responsible behavior among secondary school students.

Keywords: IoT, Micro:bit, Energy, Education, Technology.

JEL Classification: I21, O33, Q55

How to cite: Rahmawantary, D. M., Paramitra, Y., Aziza, P. F., Rahayu, D. R., Firdaus, S. S., (2026). Smart Learning for Sustainable Futures: Implementing an IoT-Based Light Detection Project Using Micro:bit Secondary Education, *Entrepreneurship and Community Development (ECD)*, 4(1), 31-41



This is an open-access article under the [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) international license

## 1. Introduction

The rapid advancement of digital technology and the Internet of Things (IoT) has significantly transformed various sectors, particularly education. The integration of smart technology into the learning process enables students to develop digital literacy, computational thinking, and problem-solving skills that are essential in the 21st century.

Educational institutions are increasingly encouraged to adopt technology-based learning approaches to prepare students for the demands of Industry 4.0 and Society 5.0. According to the World Economic Forum, digital competencies and technological adaptability are among the most critical skills required for future generations (World Economic Forum, 2023). Furthermore, technology-enhanced learning environments improve students' engagement, collaboration, and creativity in classroom activities (Kewalramani et al., 2020). The use of interactive educational technologies also supports experiential learning, allowing students to connect theoretical knowledge with practical implementation.

In Southeast Asia, the increasing demand for electricity and technological infrastructure has raised concerns regarding energy efficiency and environmental sustainability. Malaysia, for example, recorded electricity consumption reaching approximately 5,336 kWh per capita in 2023, making it one of the highest electricity-consuming countries in the region. This condition highlights the urgency of promoting energy-saving awareness, especially among younger generations. The Malaysian government has also intensified its commitment to reducing greenhouse gas emissions through sustainable energy policies and educational campaigns. Schools, therefore, play an important role in cultivating environmentally responsible behavior among students through technology-based learning programs (International Energy Agency, 2023). Integrating sustainability education with IoT projects can encourage students to understand how smart systems contribute to efficient energy management and environmental preservation (UNESCO, 2022).

One educational technology that has gained global attention is the BBC Micro:bit, a programmable microcontroller designed for beginner-friendly coding and IoT learning. Micro:bit provides a simple yet effective platform for introducing students to programming, sensors, automation systems, and embedded technology. Previous studies revealed that the use of Micro:bit significantly improves students' creative thinking, logical reasoning, and computational skills in secondary education settings (Syamsudin et al., 2023). Similarly, Voštinár and Knežník (2020) explained that Micro:bit-based learning creates an engaging classroom atmosphere because students can immediately observe the results of their programming activities. Compared to other microcontroller platforms such as Arduino, Micro:bit is considered more accessible for beginners due to its user-friendly interface, minimal hardware requirements, and visual block-based programming environment (Lim & Wardrip, 2024).

Project-Based Learning (PjBL) has become one of the most effective pedagogical approaches for implementing technology education. Through PjBL, students actively participate in solving real-world problems while collaboratively designing practical solutions. This approach promotes critical thinking, creativity, communication, and teamwork skills. Herpratiwi et al. (2022) emphasized that project-based learning encourages deeper conceptual understanding because students are directly involved in exploration and experimentation processes. In technology education, PjBL is well-suited for introducing IoT systems because students can integrate programming, electronics, and environmental awareness within a single project. Furthermore, research conducted by Bell (2021) demonstrated that hands-on technological projects increase students' motivation and self-confidence in STEM learning environments. Therefore, implementing IoT-based projects in secondary schools can be an innovative strategy to strengthen students' digital competencies.

This community service activity was conducted at Sekolah Menengah Kebangsaan Keramat Wangsa, Kuala Lumpur, involving 40 upper secondary students and three accompanying teachers in science and technology subjects. The school was selected because of its active participation in digital innovation activities and its readiness to adopt technology-enhanced learning practices. The project was implemented collaboratively by Universiti Teknologi Malaysia (UTM) and Universitas Krisnadwipayana (UNKRIS) in Jakarta as part of an international academic partnership program. The target participants consisted of Form 3 and Form 4 students who showed strong interest in science, technology, and extracurricular digital programs. Quantitatively, the workshop involved five days of activities, with approximately 8 effective training hours, conducted in the school computer laboratory equipped with internet access and basic technological facilities.

The primary problem identified in this community engagement activity was the limited exposure of secondary school students to practical IoT applications and smart energy-efficiency systems. Although students are familiar with digital devices in their daily lives, many have a limited understanding of how sensors, automation systems, and microcontrollers operate in real-world contexts. In addition, students' awareness of responsible energy consumption and sustainable technology use remains relatively low. Therefore, this program aimed to introduce IoT concepts through an interactive light-detection project using a Micro:bit, thereby improving students' understanding of smart systems and environmental sustainability. The project specifically focused on demonstrating how light sensors can automatically respond to environmental conditions to support energy-saving practices. Similar initiatives conducted in other schools have shown that IoT-based training significantly improves students' technological literacy and sustainability awareness (Sidik et al., 2024).

The objective of this community service program was to enhance students' and teachers' knowledge regarding IoT technology, digital literacy, and energy efficiency through experiential learning activities. Participants were expected to gain practical skills in programming Micro:bit devices, understanding sensor functionality, and developing simple smart systems using block-based coding. In addition, the project aimed to foster students' creativity, collaboration, and critical thinking through hands-on technological experimentation. Beyond educational outcomes, the program also intended to encourage environmentally conscious behavior by demonstrating the practical application of smart lighting systems for reducing unnecessary electricity consumption. This initiative aligns with UNESCO's vision of promoting Education for Sustainable Development (ESD) by integrating digital innovation and environmental awareness into school learning activities (UNESCO, 2022). Ultimately, the collaboration between UTM and UNKRIS reflects the importance of international academic partnerships in promoting technological innovation and sustainable education practices in Southeast Asia.

However, previous studies and community service programs on IoT-based education have predominantly focused on general programming instruction or vocational-level training, with limited emphasis on integrating sustainability awareness and energy-efficiency concepts into secondary school learning through practical smart-system projects. In addition, the implementation of beginner-friendly IoT learning platforms, such as the BBC Micro:bit, in cross-institutional international community engagement activities remains relatively underexplored. Therefore, this program contributes by combining Project-Based Learning (PjBL), IoT education, and sustainability-oriented learning within a practical light detection project designed specifically for secondary school students. The activity not only strengthens students' digital and technological competencies but also promotes environmental awareness and collaborative STEM learning through experiential and context-based educational practices.

## 2. Method

### Program Design and Approach

This community service activity adopted a participatory, project-based learning approach to introduce Internet of Things (IoT) concepts and energy-efficient technologies to secondary school students. The program was collaboratively organized by Universiti Teknologi Malaysia (UTM) and Universitas Krisnadwipayana (UNKRIS) and implemented at Sekolah Menengah Kebangsaan Keramat Wangsa, Kuala Lumpur. The activity was designed to provide experiential learning through direct practice using BBC Micro:bit devices in developing a light detection system. Project-Based Learning (PjBL) was selected because it enables students to actively engage in problem-solving activities, collaborative learning, and technology exploration. According to Herpratiwi et al. (2022), PjBL effectively enhances students' critical thinking, creativity, and practical understanding through real-world projects.

The program was conducted over five days in January 2025, totaling eight effective instructional hours. The implementation team consisted of lecturers and university students from multidisciplinary backgrounds, including electrical engineering, artificial intelligence, education,

economics, and public administration. The activities were held in the school computer laboratory equipped with internet access, laptops, and basic facilities required for digital learning. The target participants were 40 upper secondary students from Form 3 and Form 4 and three accompanying science and technology teachers. Participant selection was based on students' interest in technology-related extracurricular activities and digital innovation programs.

### **Activity Implementation Procedure**

The implementation of the IoT-based light detection project was divided into several systematic stages to ensure effective learning outcomes. The first stage involved preparation and orientation activities. Participants were introduced to the program's objectives, the concept of smart technology, and the importance of energy efficiency in everyday life. Facilitators also explained the basic functions of Micro:bit devices, sensors, and simple programming logic. This introductory session aimed to build students' conceptual understanding before entering the practical phase.

The second stage focused on hands-on technical training. Each participant received a BBC Micro:bit device, USB cable, and access to a laptop connected to the internet. Students used the MakeCode programming platform to create a simple IoT-based light detection system. Through block-based programming, participants developed a logic system that enabled the Micro:bit to detect light intensity and display different responses depending on environmental conditions. Students programmed the device using "if-else" conditional logic and continuously tested the light sensor's sensitivity across different lighting conditions. According to Voštinár and Knežník (2020), Micro:bit-based learning encourages active participation because students can directly observe the outcomes of their programming activities in real time.

The third stage involved testing, evaluation, and reflection activities. Students demonstrated their projects and explained the functionality of their systems to facilitators and peers. During this stage, facilitators provided feedback and encouraged participants to improve or customize their projects by adding additional features, such as displaying numerical light intensity values or integrating external outputs. Reflection sessions were also held to discuss how smart technology can support energy-saving practices and foster sustainability awareness in daily life.

### **Instruments and Measurement of Program Success**

The success of the community service activity was measured using descriptive qualitative and quantitative approaches. Several instruments were utilized to evaluate participants' understanding, skills development, and behavioral changes during the program. The primary instruments included observation sheets, participant questionnaires, practical assessment rubrics, and reflective discussion sessions.

Facilitators used observation sheets to assess students' participation, collaboration, problem-solving abilities, and engagement throughout the activities. The observation focused on indicators such as students' activeness during discussions, ability to operate Micro:bit devices, teamwork, and responsiveness to technical challenges. Practical assessment rubrics were used to evaluate students' ability to develop and test the light detection project successfully. Assessment criteria included programming accuracy, system functionality, creativity, and understanding of IoT concepts.

In addition, questionnaires were distributed before and after the workshop to measure changes in students' knowledge and awareness regarding IoT technology and energy efficiency. The questionnaire used a Likert-scale format to assess participants' perceptions of technology learning, digital confidence, and environmental awareness. The comparison between pre-activity and post-activity responses provided measurable indicators of learning improvement and attitude changes among participants. According to Sidik et al. (2024), microcontroller-based IoT training significantly improves students' digital literacy and technological competence when accompanied by structured evaluation methods.

Participants were selected through purposive sampling based on their interest and involvement in school science, technology, and digital innovation activities. This sampling approach was

considered appropriate because the program specifically targeted students who demonstrated motivation to participate in technology-based experiential learning. The questionnaire instrument was developed based on indicators of digital literacy, IoT understanding, programming confidence, and sustainability awareness, adapted from previous technology education studies. Prior to implementation, the questionnaire items were reviewed by facilitators and education experts to ensure content relevance and clarity. The practical assessment rubric evaluated several criteria, including programming accuracy, functionality of the light detection system, problem-solving ability, creativity, teamwork, and presentation skills. Data analysis was conducted using descriptive, qualitative and quantitative approaches. Questionnaire results were analyzed by comparing participants' responses before and after the activity to identify changes in understanding and attitudes. At the same time, observation notes and reflective discussions were interpreted descriptively to examine participant engagement, collaboration, and learning experiences during the program.

### **Indicators of Community Service Achievement**

The achievement level of this community service program was determined based on cognitive, behavioral, and socio-cultural indicators. Cognitive achievement was measured by the improvement in participants' understanding of IoT systems, programming logic, and smart technology applications. This was evident in students' ability to independently create and operate the Micro:bit-based light-detection system during the final project evaluation.

Behavioral achievement was reflected in students' increased enthusiasm, confidence, and motivation toward technology-based learning activities. Many participants showed active involvement during discussions and demonstrated curiosity in exploring additional Micro:bit features beyond the workshop materials. Teachers also observed positive changes in students' attitudes toward collaborative learning and digital experimentation.

From a socio-cultural perspective, the program increased participants' awareness of energy efficiency and responsible technology use. Through the simulation of smart lighting systems, students were encouraged to understand the importance of reducing unnecessary electricity consumption in school and home environments. This awareness represents an important initial step toward developing environmentally conscious behavior among young generations. Furthermore, the collaborative implementation between universities and schools strengthened educational partnerships and promoted the exchange of knowledge related to digital innovation and sustainability-oriented education.

## **3. Results**

### **Implementation of Community Service Activities**

The community service program entitled *“Introducing Smart Technology in Secondary Education: IoT-Based Light Detection Project Using Micro:bit at Kuala Lumpur School”* was successfully implemented at Sekolah Menengah Kebangsaan Keramat Wangsa, Kuala Lumpur, Malaysia. The activity involved 40 upper secondary school students and three accompanying teachers from science and technology subjects. The program was conducted collaboratively by Universiti Teknologi Malaysia (UTM) and Universitas Krisnadwipayana (UNKRIS) over five days in January 2025. The implementation process combined interactive presentations, demonstrations, project-based learning, and hands-on practice using BBC Micro:bit devices.

The activities began with introductory sessions on the Internet of Things (IoT), smart systems, and energy efficiency. Students were then guided to understand the functions of sensors and simple programming logic using the MakeCode programming platform. During the practical session, participants successfully developed a light detection system that measures environmental light intensity and displays automatic responses on the Micro:bit LED display. This hands-on approach enabled students to observe the relationship between coding instructions and device behavior directly. According to Voštinár and Knežník (2020), interactive Micro:bit learning activities provide meaningful educational experiences because students can immediately visualize the results of their programming processes.

The implementation of Project-Based Learning (PjBL) created an active, collaborative learning environment. Students worked in groups to solve technical problems, test sensor sensitivity, and improve their device functionality. This learning method increased students' participation and encouraged them to think critically as they developed practical technological solutions. Herpratiwi et al. (2022) stated that project-based learning effectively promotes creativity, communication skills, and independent learning among students. Throughout the workshop, facilitators observed high enthusiasm among participants, particularly during experimentation and troubleshooting.

### Indicators of Program Achievement

The success of this community service activity was measured using several indicators, including improvement in technological understanding, practical skills, digital confidence, and environmental awareness. Based on observations and evaluation results, nearly all participants were able to independently operate the Micro:bit device, create simple block-based programs, and successfully test the light detection system. Students demonstrated improved understanding regarding the role of sensors, conditional logic, and smart technology applications in everyday life. The program also had a positive impact on students' attitudes toward technology learning. Before the activity, many participants had limited knowledge regarding IoT systems and microcontroller programming. However, after participating in the workshop, students became more confident in exploring technology and showed greater interest in digital innovation projects. Teachers reported that students were more active during classroom discussions and demonstrated increased curiosity regarding coding and automation systems.

In addition to technological competencies, the activity successfully increased awareness regarding energy efficiency and sustainability. Through simulations of automatic lighting systems, participants learned how smart technologies can reduce unnecessary electricity consumption. This understanding contributed to behavioral changes among students, particularly regarding responsible energy consumption in school and home environments. UNESCO (2022) emphasized that integrating sustainability education with digital technology helps foster environmentally responsible behavior among young learners.

### Measurement Results of Community Service Outcomes

Program outcomes were measured through observation sheets, practical assessments, and participant questionnaires distributed before and after the activity. The results showed significant improvement in students' digital literacy and understanding of IoT concepts. Table 1 presents a comparison of participants' competency achievement before and after the training activity.

**Table 1. Improvement of Participants' Competencies After Training**

Assessment Indicator	Before Training (%)	After Training (%)
Understanding of IoT Concepts	35	88
Ability to Operate Micro:bit	28	92
Understanding of Sensor Functions	30	90
Programming Confidence	25	85
Awareness of Energy Efficiency	40	93

Table 1 demonstrates substantial improvement across all assessment indicators. The highest increase occurred in students' ability to operate the Micro:bit device and understand sensor functionality. This finding indicates that practical learning activities effectively enhanced students' technological competence and confidence. Sidik et al. (2024) also found that microcontroller-based IoT training significantly improves digital literacy and technical understanding among secondary school students.

### Advantages and Limitations of the Program

One of the major strengths of this program was the use of Micro:bit as an educational technology platform. The Micro:bit device is simple, affordable, and beginner-friendly, making it highly suitable for secondary school students with limited programming experience. Its block-based coding environment enabled participants to quickly understand programming logic without requiring advanced technical knowledge. Furthermore, integrating sustainability themes with IoT technology made the learning process more contextual and relevant to students' daily lives.

Another advantage was the collaborative learning environment created during the workshop. Students actively communicated, shared ideas, and worked together to solve technical challenges. This collaborative atmosphere not only strengthened technological understanding but also improved participants' teamwork and social interaction skills.

However, several limitations were also identified during program implementation. Some participants initially struggled to understand programming logic and troubleshoot device errors. Limited training duration also restricted opportunities for more advanced IoT development, such as integrating external sensors or enabling internet connectivity. Additionally, hardware devices were limited, requiring students to work in groups rather than individually.

### Opportunities for Future Development

The implementation of the IoT-based light detection project provides promising opportunities for future educational development. Schools can further integrate Micro:bit and IoT technology into STEM-based curricula and extracurricular activities to strengthen students' digital competencies. Future programs may also include more advanced projects such as smart home systems, environmental monitoring devices, or renewable energy simulations.

In addition, continuous collaboration between universities and schools can support sustainable digital literacy programs and teacher capacity development. The positive responses from participants indicate that technology-based community service activities can be effective strategies for promoting innovation, creativity, and sustainability awareness in educational environments. This initiative also demonstrates that accessible educational technologies can contribute significantly to preparing future generations for digital transformation and sustainable development challenges.



Figure 1. Students Participating in the IoT-Based Light Detection Project

#### 4. Discussion and Benefits

The implementation of the IoT-based light detection project using Micro:bit demonstrated that project-oriented and experiential learning approaches can effectively strengthen students' digital literacy, technological understanding, and sustainability awareness in secondary education. The findings indicate that participants understood IoT concepts more effectively because the learning process combined theoretical explanations with direct experimentation and real-time device interaction. This suggests that students learn technological concepts more meaningfully when abstract ideas such as sensors, automation, and conditional programming are translated into concrete, practical activities. The improvement in programming confidence and problem-solving ability was closely tied to the workshop's hands-on nature, where students actively tested, revised, and evaluated their code. These findings support the argument of Hsu and Liang (2021) that IoT-based learning environments enhance computational thinking by enabling students to interact directly with hardware systems and receive immediate feedback. Similarly, Kewalramani et al. (2020) explained that technology-integrated pedagogical practices encourage active engagement and deeper conceptual understanding through experiential learning processes.

The successful implementation of Project-Based Learning (PjBL) in this activity also provides a stronger causal explanation regarding students' increased participation and collaborative learning behavior. During the workshop, students were required to work collaboratively to solve technical challenges, analyze programming errors, and improve the functionality of their light detection systems. This collaborative process encouraged communication, peer learning, and collective problem-solving, which contributed to higher engagement and motivation throughout the activity. The findings are consistent with those of Herpratiwi et al. (2022), who found that PjBL improves students' critical thinking and learning independence by making learners active participants in constructing knowledge rather than passive recipients of information. Compared with conventional lecture-based technology instruction, the project-based approach used in this program enabled students to connect digital concepts with practical environmental applications, making the learning experience more contextual and relevant to everyday life. Bell (2021) also emphasized that authentic technology projects increase students' motivation because learners can observe the direct impact of their work on solving real-world problems.

Another important finding of this activity concerns the role of the Micro:bit as an accessible educational technology platform for beginner-level IoT learning. The use of visual block-based programming reduced students' anxiety toward coding activities and enabled participants with limited technical backgrounds to understand programming logic more quickly. This condition explains why participants demonstrated higher confidence and willingness to explore additional technological features during the workshop. The results align with those of Syamsudin et al. (2023), who reported that Micro:bit-based learning significantly improves students' creativity and confidence in informatics education. Compared with more complex microcontroller platforms, the Micro:bit provides a simpler learning environment that supports gradual technological adaptation for secondary school students. Voštinár and Knežník (2020) similarly noted that students become more motivated when programming outputs can be directly visualized through interactive device responses. Therefore, the effectiveness of this program was not only influenced by the learning approach but also by the suitability of the educational technology used in the activity.

From a sustainability perspective, integrating energy-efficiency themes into IoT learning fostered students' environmental awareness and responsible technology behavior. Through the automatic light detection simulation, participants were introduced to the practical role of smart systems in reducing unnecessary electricity consumption. The findings suggest that combining environmental issues with technology education can create more meaningful and socially relevant learning experiences for students. UNESCO (2022) emphasized that sustainability-oriented education should encourage learners to develop practical solutions to environmental challenges through interdisciplinary learning. In this activity, sustainability concepts were not merely delivered theoretically but embedded directly into the project design, enabling students to understand the relationship between technological innovation and environmental responsibility. Compared with

previous technology training programs that focused primarily on technical competencies, this activity provided additional value by integrating digital literacy with sustainability education and behavioral awareness.

The program also generated broader community-development benefits through the strengthening of school-university collaboration and the promotion of digital empowerment within educational environments. The partnership between Universiti Teknologi Malaysia (UTM) and Universitas Krisnadwipayana (UNKRIS) created opportunities for knowledge exchange, technological mentoring, and international educational collaboration. This collaboration contributed not only to students' learning experiences but also to teachers' understanding of innovative STEM teaching practices that can be implemented in future classroom activities. Recent studies have shown that community-based digital literacy programs can strengthen educational resilience and technological readiness within local communities (Aisyah & Novita, 2025). In addition, Isnaini et al. (2025) highlighted that digital literacy initiatives contribute to long-term educational empowerment by improving participants' adaptability to technological transformation. Therefore, this community service activity can be viewed not only as a short-term training program but also as part of a broader effort to support sustainable educational development and digital inclusion.

Despite the positive outcomes, several limitations influenced the implementation process and the depth of learning achieved during the activity. Some participants initially struggled to understand coding structures and troubleshoot technical errors, particularly those with limited prior programming experience. The relatively short duration of the workshop also limited opportunities to introduce more advanced IoT applications, such as cloud-based monitoring systems and internet-connected automation. These findings indicate that continuous mentoring and longer-duration programs are necessary to achieve deeper technological mastery and sustainable learning outcomes. Sidik et al. (2024) similarly argued that sustained microcontroller training programs are more effective in strengthening students' digital competence and technological readiness than one-time workshops. Future community service initiatives should therefore incorporate follow-up mentoring, advanced project development, and teacher training programs to ensure the long-term sustainability and wider educational impact of IoT-based learning activities in schools.

Overall, the discussion demonstrates that the combination of Project-Based Learning, beginner-friendly IoT technology, and sustainability-oriented educational content can effectively improve students' digital competencies, collaborative skills, and environmental awareness. The activity also illustrates how community service programs can contribute to educational empowerment by bridging academic knowledge with practical societal needs. By integrating technological innovation with sustainability education, the program provided students with the relevant competencies to address future digital transformation challenges while simultaneously encouraging responsible, environmentally conscious behavior.

## 5. Conclusion

The implementation of an IoT-based light detection project using Micro:bit successfully enhanced students' understanding of Internet of Things concepts, programming logic, and energy efficiency through experiential and project-based learning activities. The program demonstrated that integrating beginner-friendly IoT technology with Project-Based Learning (PjBL) can strengthen students' digital literacy, collaboration skills, problem-solving abilities, and engagement in STEM education. In addition, integrating sustainability themes into practical technological activities enabled students to connect digital innovation with environmentally responsible behavior. The collaboration between universities and schools also facilitated knowledge exchange and supported the development of technology-oriented educational practices in secondary schools.

This activity indicates that IoT-based learning programs have strong potential to support digital transformation and sustainability-oriented education in schools. However, the program was constrained by the short implementation period, limited device availability, and a focus on basic IoT applications rather than advanced internet-connected systems. Therefore, future community service initiatives should involve longer mentoring periods, broader participation, and more

advanced smart technology projects, such as environmental monitoring and cloud-based automation systems. Continuous teacher training and periodic evaluation are also necessary to ensure the sustainability and long-term educational impact of technology-based learning programs.

### Recommendations

Schools are recommended to integrate IoT- and Micro:bit-based learning activities into STEM subjects within one academic year through phased curriculum implementation and extracurricular programs. Teacher training on Project-Based Learning and basic IoT programming should be conducted at least once every semester to strengthen instructional capacity and technological adaptation. Educational institutions are also encouraged to provide a minimum device allocation ratio of 1 Micro:bit per 2 students to support more intensive hands-on practice. Follow-up evaluations should be conducted periodically, using indicators such as students' digital literacy improvement, project completion quality, programming confidence, collaboration skills, and sustainability awareness to measure the long-term educational impact effectively.

### Limitations and avenues for future community services

This community service activity was limited by the short training duration, the limited number of Micro:bit devices, and the focus on basic IoT applications without advanced internet connectivity features. The evaluation mainly relied on descriptive observations and participant responses, which may limit broader generalization of the findings. Future community service programs are recommended to involve longer implementation periods, larger participant groups, and more advanced smart technology projects, such as environmental monitoring and cloud-based IoT systems, to strengthen students' digital competencies and sustainability awareness.

### References

- Aisyah, S., & Novita, D. (2025). Teachers' perception of the implementation of project-based learning in early childhood education in Indonesia. *Cogent Education*, 12(1). <https://doi.org/10.1080/2331186X.2025.2458663>
- Arifin, Z. (2021). Renewable energy: A solution for Indonesia's energy resilience. *HAGA: Jurnal Pengabdian Kepada Masyarakat*, 2(1), 45–52. <https://jurnal.uniraya.ac.id/index.php/HAGA/article/view/2208>
- Bell, S. (2021). Project-based learning for the 21st century: Skills for the future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 94(2), 39–43. <https://doi.org/10.1080/00098655.2021.1878823>
- Herpratiwi, T., et al., (2022). Implementation of project-based learning based on social skills in civic education subjects at high school. *Edukatif: Jurnal Ilmu Pendidikan*, 4(1), 123–130. <https://repository.lppm.unila.ac.id/32340/>
- Hsu, T. C., & Liang, Y. C. (2021). The effects of IoT-based learning environments on students' computational thinking skills. *Education and Information Technologies*, 26(4), 4121–4139. <https://doi.org/10.1007/s10639-021-10412-5>
- International Energy Agency. (2023). *Southeast Asia Energy Outlook 2023*. IEA Publications. <https://www.iea.org/>
- Isnaini, M., et al. (2025). The role of digital literacy in social media. *Mimbar Media Sosial*, 6(1), 58–74. <https://doi.org/10.12928/mms.v6i1.12242>
- Kewalramani, S., et al. (2020). Technology-integrated pedagogical practices: A look into evidence-based teaching and coherent learning for young children. *European Early Childhood Education Research Journal*, 28(2), 163–166. <https://doi.org/10.1080/1350293X.2020.1735739>
- Lim, J., & Wardrip, P. (2024). Technology integration as a spectrum: Integrating technology in early childhood classrooms. *Teachers and Teaching*, 1–19. <https://doi.org/10.1080/13540602.2024.2420137>
- Sidik, D., et al. (2024). IoT-based microcontroller trainer media: Innovation for vocational education essential programs. *International Journal of Latest Technology in Engineering, Management & Applied Science*, 13(11), 6–10. <https://doi.org/10.51583/IJLTEMAS.2024.131102>

- Syamsudin, M. S., et al. (2023). Improving students' creative thinking skills using BBC Microbit in informatics subjects. *Cendikia: Media Jurnal Ilmiah Pendidikan*, 13(4), 1–10. <https://doi.org/10.35335/cendikia.v13i4.3637>
- UNESCO. (2022). *Education for sustainable development: Learning objectives and implementation strategies*. UNESCO Publishing. <https://unesdoc.unesco.org/>
- Voštinár, P., & Knežník, J. (2020). Education with BBC micro:bit. *International Journal of Online and Biomedical Engineering (iJOE)*, 16(14), 81–89. <https://doi.org/10.3991/ijoe.v16i14.17071>
- World Economic Forum. (2023). *The future of jobs report 2023*. World Economic Forum. <https://www.weforum.org/>