Journal of Dedication in Community (JoDiC)
Vol. 03, Issue. 02, Page. 32 - 41
ISSN: 3026-0760

Integrating Physics Concepts into Practical Learning through Smart Robot Projects for High School Students in SMAN 3 Pamekasan Madura

Ersyzario Edo Yunata*[1], Imam Sapuan[1], Nuril Ukhrowiyah[1], Evi Suaebah[2]
[1]Universitas Airlangga, Surabaya, Indonesia
[2]Universitas Negeri Surabaya, Surabaya, Indonesia

DOI:

Article Info

Article Info:
Received 8 December 2025
Revised: 9 December 2025
Accepted: 10 December 2025
Published: 11 December 2025

Keywords:
Community Service
Smart robot
Line follower
Fire extenguisher robot

ABSTRACT

This community service program was designed to integrate fundamental physics concepts into practical learning through the implementation of smart robot projects, aiming to enhance students' comprehension and interest in physics. Conducted at SMAN 3 Pamekasan, Madura, the program involved the design, assembly, and functional testing of four line follower robots and one water-based fire extinguisher robot. Preparatory stages included intensive prototyping and coding trials at the Electronics Laboratory, Department of Physics, Universitas Airlangga, followed by a field survey to the school to assess readiness and requirements. The main activity engaged students in hands-on tasks, encompassing mechanical assembly, electronic circuit integration, and programming, thereby enabling them to directly observe the application of physics principles in robotics. Evaluation using pre-test and post-test instruments indicated a measurable improvement in understanding, with average scores rising from 6.83 to 7.42. These results demonstrate the effectiveness of project-based learning in fostering not only cognitive gains but also positive attitudes toward physics by reframing it as an applied and engaging discipline rather than purely theoretical.

INTRODUCTION

Physics education in Indonesian high schools often prioritizes abstract theories and mathematical problem-solving, leading to a common perception that physics is a challenging and disconnected subject. This perception, in turn, causes many students to view physics as merely an academic requirement for passing exams rather than recognizing its practical applications in modern technology. Therefore, bridging the gap between theoretical concepts and real-world applications is crucial to fostering genuine interest and long-term engagement with physics.

Research has demonstrated that project-based learning (PBL) enhances student motivation and deepens conceptual understanding by linking abstract principles to tangible products (Kokotsaki et al., 2016; Thomas, 2000). Among various educational approaches, educational robotics has proven to be an effective multidisciplinary tool that integrates physics, electronics, engineering design, and problem-solving skills (Benitti, 2012). Studies have also indicated that robotics projects improve students' understanding of STEM concepts and promote collaborative learning (Alimisis, 2013). While robotics-based physics learning has been introduced in some urban schools in Indonesia, such programs remain rare in rural and peripheral areas, where access to technology and trained facilitators is limited.

The novelty of this program lies in its combination of two levels of robotics complexity: a line follower robot and a fire-fighting robot, used progressively to introduce physics concepts. The line follower robot, which uses a minimal number of infrared sensors, allows students to focus on basic electronics, light reflection, and motor control. In contrast, the fire-fighting robot integrates multiple sensor types, including flame sensors, ultrasonic sensors, and a water pump system, requiring students to manage sensor fusion, actuator control, and more advanced programming logic. This

Journal of Dedication in Community (JoDiC)
Vol. 03, Issue. 02, Page. 32 - 41
ISSN: 3026-0760

tiered approach provides a clear learning progression from fundamental concepts to complex system integration, which is rarely applied in high school-level physics outreach in rural Indonesia.

The primary issue addressed by this community service program is the limited exposure of students at SMAN 3 Pamekasan to practical applications of physics using modern technology. Located in Pamekasan Regency, Madura Island, the school serves students from diverse socioeconomic backgrounds, with limited access to robotics kits and structured STEM innovation programs. Despite having a dedicated science faculty, the school faces resource constraints and limited opportunities for students to engage in hands-on, technology-based learning. Given these conditions, the program was designed to (1) introduce robotics as a medium for applying physics principles in an engaging, hands-on manner; (2) build students' technical skills in sensor operation, mechanical assembly, and programming; (3) demonstrate the relevance of physics in modern technological solutions; (4) address student difficulties with key physics concepts such as electrical circuits and sensor logic; and (5) encourage students to view physics as a creative and impactful discipline, rather than a mere abstract subject.

This article presents the implementation and outcomes of the community service program that integrated physics concepts into robotics projects at SMAN 3 Pamekasan. The study describes the design of the robotics activities, the pedagogical rationale behind the tiered robot selection, the impact on students' understanding of physics as measured by pre-test and post-test results, and the broader implications for STEM education in similar school contexts.

.

CASE STUDY

Community service programs in education often aim to bridge the gap between formal school curricula and innovative pedagogical practices that are not yet widely adopted. In Indonesia, several studies have demonstrated the effectiveness of community-based interventions in enhancing students' engagement and achievement in science learning (Merdekawati et al., 2022; Rahmi et al., 2023). These initiatives provide not only enrichment activities for students but also capacity-building opportunities for teachers, thereby contributing to sustainable educational development.

In the field of science education, project-based learning (PBL) has been identified as a powerful approach to promote student-centered learning. PBL encourages learners to actively construct knowledge by working on real-life projects, thus improving motivation, problem-solving abilities, and conceptual understanding (Thomas, 2000; Kokotsaki et al., 2016). Within physics education, PBL has been particularly effective in connecting abstract principles with tangible experiences, making it highly relevant for outreach and community service contexts.

Educational robotics has emerged as a practical tool within PBL to integrate multiple STEM domains, including physics, electronics, programming, and engineering design. Robotics projects provide learners with opportunities to experiment, troubleshoot, and apply scientific reasoning in a hands-on environment. Prior research indicates that robotics-based learning enhances both cognitive skills and positive attitudes toward science subjects (Benitti, 2012; Alimisis, 2013). In Indonesia, robotics education has been applied in limited contexts, primarily in urban schools or extracurricular programs, while rural schools still face significant challenges in terms of resources and trained facilitators (Wahyuni & Andriani, 2023)

Community service activities that introduce robotics in under-resourced schools therefore offer dual benefits: they increase students' exposure to modern technology while simultaneously reinforcing the relevance of physics as a discipline. Previous service-learning programs have shown that when students engage in robotics activities guided by facilitators, their scientific literacy and collaboration skills improve significantly (Susilana et al., 2023). Such findings highlight the importance of robotics-based community service as a means to democratize access to STEM education, particularly in peripheral regions such as Madura.

In summary, the literature indicates that combining PBL and robotics in community service initiatives not only addresses educational gaps but also provides a sustainable model for enhancing physics education in Indonesia. This study builds on these insights by implementing a tiered robotics program in SMAN 3 Pamekasan, designed to progressively introduce physics concepts through line follower and fire-fighting robots

METHOD

This community service program was implemented using a participatory and project-based learning (PBL) approach**.** The method was designed to engage students actively in the process of designing, assembling, and testing smart robots, while simultaneously integrating fundamental physics concepts into practical activities. The procedures consisted of four main stages:

1. *Preparation*

The program began with intensive prototyping and coding trials at the Electronics Laboratory, Department of Physics, Universitas Airlangga. Four line follower robots and one fire-fighting robot were assembled and tested to ensure functionality and reliability. During this stage, facilitators refined the mechanical design, electronic circuits, and programming codes to adapt the robots to the skill levels of high school students.

2. *Field Survey*

A preliminary survey was conducted at SMAN 3 Pamekasan, Madura to assess the school's readiness, technical requirements, and available facilities. This step involved discussions with teachers to align activities with the school's curriculum and identify potential challenges students face in accessing robotics-based learning.

3. *Implementation*

The main activity was carried out through a series of hands-on workshops in August 1, 2025 at SMAN 3 Pamekasan. Students were divided into small groups and guided to:

- Perform mechanical assembly of robot components.
- Integrate electronic circuits and sensors.
- Develop simple programming codes to control the robots. Two levels of robotics complexity were introduced:

a. *Line follower robots* (basic level), focusing on sensor operation, light reflection, and motor control.
b. *Fire-fighting robot* (advanced level), which required integration of flame sensors, ultrasonic sensors, water pump actuators, and sensor fusion programming.

4. *Evaluation*

Journal of Dedication in Community (JoDiC)
Vol. 03, Issue. 02, Page. 32 - 41
ISSN: 3026-0760

To measure the effectiveness of the program, pre-test and post-test instruments were administered to 25 participating students. The test items assessed basic physics concepts related to mechanics, electricity, and sensor technology. Quantitative analysis compared the average scores before and after the activity, while qualitative observations documented changes in students' enthusiasm, teamwork, and problem-solving skills.

RESULT AND DISCUSSION

The community service program was successfully implemented at SMAN 3 Pamekasan, Madura, involving 25 high school students in a series of robotics workshops. The activities were divided into mechanical assembly, electronic circuit integration, and programming tasks. Students produced four functional line follower robots and one fire-fighting robot during the program.

Figure 1. Student of SMAN 3 Pamekasan Participating in Robot Assembly Workshop
Source: Author's Documentation, 2025

The picture shows students of SMAN 3 Pamekasan actively participating in the robotics workshop. They are divided into small groups, each focusing on assembling and testing their line follower robots. The white track paper placed on the floor was used as a testing arena for the robots, allowing students to directly observe the relationship between infrared sensors, light reflection, and motor control.

This activity illustrates the hands-on and collaborative nature of the program. Students not only applied physics concepts in a practical setting but also developed teamwork and problem-solving skills. The classroom atmosphere, as documented in the picture, reflects a high level of enthusiasm and engagement, supporting the observation that robotics projects increase motivation and make physics more approachable and enjoyable for students.

Improvement in Student Learning Outcomes

Evaluation of the improvement in students' learning outcomes was carried out through pre-test and post-test instruments consisting of 10 questions related to applied physics concepts in smart robotics, including optical sensors, analog–digital signals, microcontrollers, signal processing, and control systems. A total of 25 students participated in the entire series of activities. The pre-test score distribution indicated that the students' initial conceptual understanding was still limited. The highest frequency category was score 8 achieved by 11 students, followed by score 7 achieved by 6 students, while no participant obtained a perfect score of 10. This shows that although some students had basic knowledge of instrumentation physics, they were not yet able to associate it with robotics implementation.

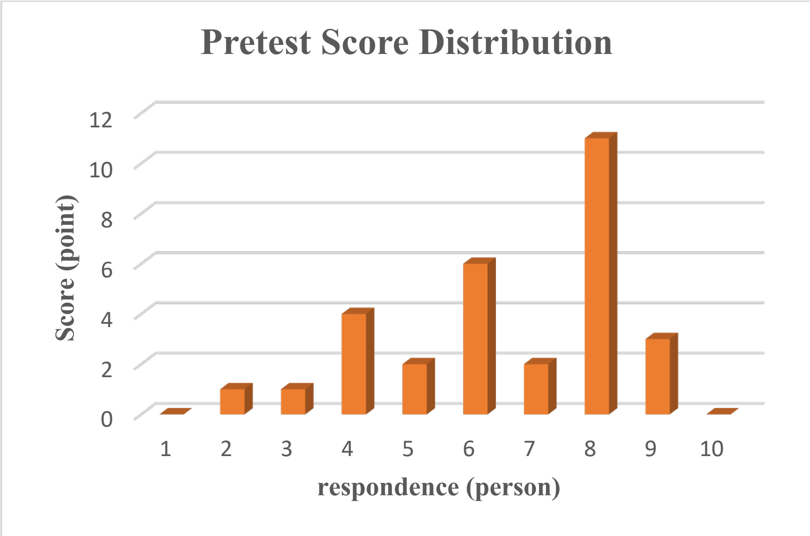

Figure 2. Distribution of Students' Pre-test Scores

Following the implementation of the project-based workshop, post-test scores showed a substantial improvement. The highest score of 10 was achieved by 4 students, while score 8 was achieved by 7 students. No students remained in the low-score category (≤3). This shift indicates enhanced cognitive ability in understanding the relationship between physics theory and the implementation of smart robot components following direct practice.

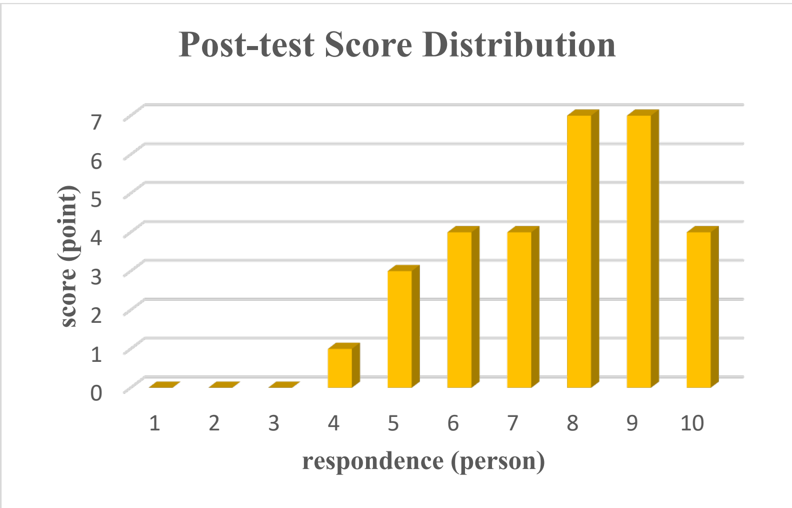

Figure 3. Distribution of Students' Post-test Scores

The increase in test scores confirms that the use of smart robotics experiments as a learning medium is effective in significantly improving students' understanding of physics concepts. The shift of the majority of students to the high-score category demonstrates that experiential learning and problem-solving practice produced a strong academic impact.

Learning Motivation and Engagement

Throughout the activity, students demonstrated a gradual yet consistent increase in motivation and learning engagement. During the initial phase of the workshop, most students were hesitant to take initiative and relied heavily on step-by-step instructions from the facilitators. Their involvement was still limited to procedural compliance rather than active exploration. However, once students began to perceive the direct cause-and-effect relationship between modifying lines of code and observing changes in robot movement, their attitude transformed. The realization that their decisions had a visible and immediate impact on the physical behavior of the robot acted as a strong psychological trigger for enthusiasm.

As the learning sessions progressed, students increasingly participated in problem-solving dialogues, compared code snippets, and negotiated alternative solutions within their groups. They voluntarily repeated trials not merely to "complete the task" but to attain improvements and stability in robot performance, which signaled a shift from task-oriented behavior to mastery-oriented learning. The workshop environment turned vibrant, with students discussing debugging strategies, sharing practical tips with peers, and showing genuine excitement when updated programs produced better outcomes on the robot's trajectory.

This continued participation reflected more than momentary excitement; it illustrated deep affective engagement that supported cognitive growth. Students who were initially uncertain or passive began displaying persistence and resilience when failures occurred, treating them as an integral part of discovery rather than signs of inability. The hands-on nature of robotics created an emotional investment in the results of experimentation, stimulating a higher willingness to analyze and internalize physics concepts to achieve desirable robot behavior. In this way, motivation acted not only as a reaction to learning success but as a driver that strengthened conceptual understanding continuously throughout the activity.

Implementation Reflection and Output

During the implementation of the project-based workshop, students repeatedly encountered situations where the robot did not behave as expected. Instead of perceiving these moments as setbacks, many students engaged in systematic attempts to identify problems, ranging from revisiting the logic flow of their code to examining sensor alignment and environmental conditions on the track. These troubleshooting efforts encouraged them to break down complex problems into smaller, manageable components and think through the consequences of each programming or mechanical decision. This indicated the emergence of technical reasoning and reflective learning that is fundamental to STEM education.

Journal of Dedication in Community (JoDiC)
Vol. 03, Issue. 02, Page. 32 - 41
ISSN: 3026-0760

Figure 4. Implementation and Learning of Intelligent Robots
Source: Author's Documentation, 2025

Each attempt triggered new hypotheses, followed by experimentation and evaluation. Students began predicting possible effects of altering thresholds in the code, adjusting delay values, or refining sensor calibration to achieve smoother directional control. Through repeating this try-and-improve cycle, they implicitly practiced scientific reasoning without needing to be explicitly instructed to follow a "scientific method." The refinement process became increasingly deliberate and analytical as they realized that robot performance reflected the precision of their conceptual understanding. The transition from trial-and-error behavior toward hypothesis-driven experimentation marked a significant cognitive shift in the learning process.

The final working product — a line follower robot capable of completing the path consistently and without major error — embodied the cumulative learning outcomes generated throughout the workshop. It represented not merely technical success but evidence that students had gone beyond rote execution to system-level understanding. The robot's performance made their internal knowledge visible: every modification to the program, circuit connection, or sensor placement showed up directly in the robot's movement. The sense of achievement that came from observing the robot succeed on the track reinforced confidence, strengthened conceptual retention, and validated students' belief that physics principles are not abstract theories but dynamic systems that can be engineered and controlled. Ultimately, the tangible success of the robot functioned as both an instructional output and a motivational reward, illustrating the depth of understanding made possible through hands-on, reflective learning experiences.

Discussion

The findings of this activity indicate that smart-robotics-based physics learning consistently enhances students' conceptual understanding by integrating theoretical knowledge with direct practical experience. The significant improvement in post-test scores demonstrates that students not only memorized concepts but gained the ability to understand the relationship between sensors, programming logic, mechanical signals, and robotic responses in real-world contexts. Such learning creates an authentic

Journal of Dedication in Community (JoDiC)
Vol. 03, Issue. 02, Page. 32 - 41
ISSN: 3026-0760

experience that enables knowledge internalization through interaction with tangible robotic systems rather than through passive delivery of information. This aligns with the meta-analysis by Ouyang and Xu (2024), which confirmed that robotics significantly improves conceptual understanding in STEM learning because it provides observable and manipulable context for abstract ideas.

Robotics-based learning also transforms learning behavior from passive into investigative. When the robot failed to respond as expected, students were stimulated to observe causality, design alternative solutions, modify code, and test improvements iteratively until optimal performance was achieved. This cycle of experimentation, evaluation, reflection, and refinement strengthened conceptual understanding without explicit instruction to follow a "scientific method." Similarly, Addido *et al.* (2023) reported that robotic trial-and-error situations act as a natural stimulus for learning because students must apply physics reasoning to identify the source of the problem and implement effective corrections.

Figure 5. Presentation by Alif Fauzan Farhani
Source: Author's Documentation, 2025

Beyond cognitive gains, project-based robotics also activates affective dimensions of learning that are difficult to achieve through traditional lectures. Students' emotional involvement in both successful and unsuccessful robot trials generated curiosity and persistence in understanding the underlying physics concepts. Instead of learning physics due to evaluation demands, they were intrinsically motivated to see their robot perform accurately. This phenomenon is in line with the findings of Trapero-González *et al.* (2024), who indicated that robotics strengthens scientific perseverance and inquiry because students feel directly responsible for the engineering and experimentation processes.

Overall, integrating robotics into physics learning is a modern, contextual, and experience-oriented pedagogical approach that is highly relevant for secondary education. It allows students to see abstract concepts as real systems they can control, making learning more meaningful and impactful. Besides enhancing academic achievement, robotics also strengthens students' technological literacy—an increasingly essential skill in today's educational ecosystem. This aligns with the recent literature review by Windrawan (2024), which emphasized the dual benefit of robotics-integrated learning: improved physics mastery and increased readiness for 21st-century technology.

CONCLUSION

Smart-robotics-based learning demonstrated a strong and meaningful impact on students' achievement in applied physics. The substantial improvement from pre-test to post-test results shows that students not only acquired theoretical knowledge about sensors, signal processing, and control systems, but were also able to apply this knowledge directly to real robotic mechanisms. This indicates that hands-on learning experiences successfully bridge the gap between physics concepts and real-world application, thereby accelerating the construction of conceptual understanding. Beyond cognitive improvement, the learning process fostered motivation, confidence, and persistence in solving technical challenges. The opportunity to repeatedly design, test, and evaluate robot performance created emotional and intellectual engagement that prompted students to explore physics more deeply. Such engagement does not emerge from lecture-based learning alone and highlights the potential of robotics to stimulate curiosity, enjoyment, and problem-solving skills simultaneously. Based on these outcomes, robotics-based learning is recommended as an effective instructional strategy for secondary-level physics education. Future programs may consider extending the duration of activities, incorporating more diverse robotic modules, and integrating interdisciplinary tasks to further strengthen students' technological literacy and scientific reasoning. Follow-up research is also encouraged to measure long-term knowledge retention and to evaluate the scalability of robotics-based physics learning in broader school environments.

ACKNOWLEDGMENT

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirm that all data, analysis, and content presented in this manuscript are original and free from plagiarism.
The authors would like to express their sincere appreciation to SMAN 3 Pamekasan for the warm collaboration and enthusiasm throughout the community service activity. The authors also extend their gratitude to the Faculty of Science and Technology, Universitas Airlangga, for providing support, facilities, and funding that enabled both the implementation of the program and the completion of this manuscript.

REFERENCES

Alimisis, D. (2013). Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education, 6*(1), 63–71.

Addido, J., Duverger, L., & Martínez, R. (2023). *Teaching Newtonian physics with LEGO EV3 robots: An integrated STEM approach. Eurasia Journal of Mathematics, Science and Technology Education*, 19(4), 1–14.

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58*(3), 978–988. https://doi.org/10.1016/j.compedu.2011.10.006

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Merdekawati, D., Astuti, A., & Puspita, M. (2022). Penggunaan drill method dalam perilaku hidup bersih dan sehat sebagai pencegahan COVID-19. *Jipemas: Jurnal Inovasi Hasil Pengabdian Masyarakat, 5*(2), 331–342.

Ouyang, F., & Xu, W. (2024). *The effects of educational robotics in STEM education: A multilevel meta-analysis*. *International Journal of STEM Education*, 11(1), 1–18.

Rahmi, F. N., Wijayanti, S., Novianty, S. M., & Utami, I. P. T. (2023). Edukasi pola komunikasi keluarga dalam menghadapi pandemi COVID-19 pada Lembaga Pendidikan Anak Usia Dini. *Wikrama Parahita: Jurnal Pengabdian Masyarakat, 7*(2), 171–182.

Susilana, R., Hernawan, A. H., Hadiapurwa, A., Syafitri, N. K., Halimah, L., & Nugraha, H. (2023). Pembinaan pengembangan kurikulum merdeka berbasis best practices program Sekolah Penggerak. *Jurnal Pengabdian Kepada Masyarakat, 29*(1), 13–18.

Thomas, J. W. (2000). A review of research on project-based learning. *Autodesk Foundation*. Retrieved from http://www.bie.org

Trapero-González, I., Romero-Rodríguez, J. M., Fernández-Martín, F. D., & Alonso-García, S. (2024). *Educational robotics and STEM competence: Systematic review and meta-analysis*. *Frontiers in Education*, 9, 1–15.

Wahyuni, S., & Andriani, R. (2023). Pelatihan pemanfaatan Google Form sebagai media evaluasi dalam model pembelajaran hybrid learning. *Dinamisia: Jurnal Pengabdian Kepada Masyarakat, 7*(2), 419–425.

Windrawan, I. G. (2024). *Bibliometric analysis of robotics-based STEM learning in physics education*. *Journal of Physics Education Studies*, 10(1), 22–34.

Ersyazario Edo Yunata (Corresponding Author)
Universitas Airlangga
Jl. Jalan Dr. Ir. H. Soekarno, Mulyorejo, Surabaya, Jawa Timur 60115
Email: ersyzario.edo@fst.unair.ac.id