



From Line to Logic: STEM Learning Based on Line Follower Robot Program for Vocational Students' Logical Thinking Development

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Abstract

In the current digital era, logical thinking skills and technological understanding are increasingly essential for vocational high school (SMK) students preparing to enter a technology-driven workforce. This community service program aimed to strengthen students' logical thinking skills through STEM-based learning activities focused on the configuration and programming of line follower robots. The program was conducted over one month and comprised three stages: focus group discussion with school partners, development of instructional materials, and training sessions. The training involved 17 students. Participants were introduced to fundamental concepts of line follower robots, including basic logic, sensors, and programming principles, and then applied this knowledge through practical tasks. Evaluation results showed that 76% of students expressed increased interest in further learning robotics, while all participants (100%) successfully completed the assigned task of programming the robot to navigate from the starting point to the finish line. These findings indicate that robotics-based learning effectively supports the program's objective of enhancing logical thinking while simultaneously increasing students' engagement with STEM concepts. By integrating theoretical explanations with direct practice, the line follower robot served as an accessible and meaningful medium for translating abstract logical reasoning into concrete technological applications. The main contribution of this community service activity lies in offering an applied STEM learning model for vocational high schools, particularly in contexts with limited prior exposure to robotics. This program provides a practical reference for integrating educational robotics into SMK learning environments to strengthen logical reasoning, technical competence, and students' motivation to pursue STEM-related fields.

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INTRODUCTION

In today's digital era, the ability to think logically and understand technology has become increasingly essential, especially for students in vocational high schools (SMK in Indonesian Acronym) who are being prepared to enter the workforce directly. One effective approach to developing these skills is through learning activities that integrate both theory and hands-on practice (Rafidiyah & Kailani, 2020; Wahyuni et al., 2021; Yusadinata et al., 2021). However, several national reports indicate that many vocational graduates still experience difficulties in developing higher-order thinking skills and practical technological competencies aligned with industry needs.

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According to the Directorate General of Vocational Education of the Indonesian Ministry of Education, learning practices in many vocational schools remain predominantly theoretical, with limited opportunities for hands-on problem-solving and technology-based activities (DITJEN Pendidikan Vokasi Kemendikdasmen, 2023). This condition contributes to a mismatch between the competencies developed in vocational education and the skills required in contemporary technology-driven industries. This mismatch between educational outcomes and labor market demands represents a structural problem that requires innovative, practice-oriented learning interventions.

From a global development perspective, this issue is closely aligned with the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 8 (Decent Work and Economic Growth). SDG 4 emphasizes inclusive and equitable quality education that promotes lifelong learning opportunities, including the development of relevant technical and cognitive skills. Meanwhile, SDG 8 highlights the importance of productive employment and a skilled workforce capable of supporting sustainable economic growth. Strengthening logical thinking and technological literacy among SMK students through applied STEM learning directly contributes to both goals by enhancing employability and workforce readiness (McGrath & Russon, 2023; Nurjanah & Ana, 2022).

Despite policy commitments to strengthen STEM-based vocational education, several institutional reports reveal persistent challenges in its implementation. For example, reports from the Directorate General of Vocational Education of the Indonesian Ministry of Education indicate that many vocational schools still rely heavily on theoretical instruction with limited integration of hands-on STEM learning activities (DITJEN Pendidikan Vokasi Kemendikdasmen, 2023). Similar concerns have also been highlighted in international reports such as the OECD Education at a Glance report, which notes that vocational education systems often face difficulties in aligning training practices with rapidly evolving technological competencies (Organisation, 2023). The Indonesian Ministry of Education has reported that learning in SMKs remains predominantly theoretical, with limited integration of hands-on, problem-based activities that foster logical and computational thinking (DITJEN Pendidikan Vokasi Kemendikdasmen, 2023). Internationally, similar concerns have been reported in the literature. Several studies indicate that vocational students often face difficulties in transferring theoretical knowledge into practical problem-solving contexts. For example, the OECD *Education at a Glance* report highlights that many vocational education systems struggle to ensure that students acquire applied technological competencies aligned with workplace demands (Indicators, 2023). Similarly, Meylani (2025) notes that gaps frequently emerge between conceptual learning in classrooms and students' ability to apply these concepts in authentic technological or engineering tasks. These findings suggest that vocational education requires more practice-oriented and experiential learning approaches to effectively bridge the gap between theory and application. These findings underscore the urgency of developing learning models that explicitly bridge theory and practice through authentic technological applications.

Logical thinking is a vital cognitive skill in both education and everyday life, particularly in robotics and programming activities, logical thinking plays a crucial role in enabling students to analyze system behavior, interpret sensor inputs, and formulate appropriate control decisions. It enables individuals to analyze situations, identify problems, and develop effective solutions. In vocational education, logical reasoning plays a critical role in understanding system behavior, troubleshooting technical problems, and making informed decisions in real-world work environments. However, several studies indicate that logical thinking skills among vocational students are often underdeveloped due to limited exposure to contextualized problem-solving tasks (Auniyah et al., 2020; Punia et al., 2022). In robotics and programming activities, logical reasoning enables students to construct algorithmic steps, interpret sensor data, and determine appropriate system responses during task execution. According to (Johnson-Laird, 2006), logical thinking is a foundational cognitive skill that enables individuals to analyze conditions, identify causal relationships, and formulate systematic solutions. This gap highlights the need for instructional strategies that explicitly train logical reasoning within applied technological contexts.

Robotics education has emerged internationally as an effective approach for integrating logical thinking, programming, electronics, and system control within a single learning framework. In vocational education settings, robotics learning is commonly implemented through project-based activities such as robot assembly, sensor integration, and basic programming tasks that simulate real industrial automation systems. These activities allow students to apply theoretical knowledge in

practical technological contexts while developing problem-solving and computational and logical thinking skills. Robotics represents a multidisciplinary field that combines mechanical systems, electronics, and software-based control to perform autonomous or semi-autonomous tasks (Alatise & Hancke, 2020; Hendrik & Awal, 2023). Educational robotics has been shown to enhance students' understanding of STEM concepts, improve problem-solving abilities, and foster creativity and collaboration (Barak & Zadok, 2007; Benitti, 2012; Eguchi, 2014) In vocational settings, robotics-based learning is particularly relevant because it mirrors industrial automation and control systems commonly used in modern workplaces.

Among various educational robotics platforms, the line follower robot is widely recognized as an effective introductory system (Budiyanta et al., 2020; Nugraha et al., 2026; Serrano Pérez & Juárez López, 2019). A line follower robot operates by detecting and following a predefined path using sensors typically infrared sensors connected to a microcontroller that processes input signals and controls actuators such as DC motors (Akbar et al., 2024; Priambodo et al., 2024; Yantidewi et al., 2022). Typically, infrared (IR) sensors or phototransistors placed on the underside of the robot detect the contrast between the line and the background. The microcontroller processes the input from these sensors and sends commands to the actuators to control the robot's movement (Fathoni, 2025; Gumilang et al., 2023; Widayaka et al., 2024). Although technically simple, this system embodies essential engineering concepts, including sensor data processing, logical decision-making, control algorithms, and debugging. Prior studies have demonstrated that line follower robots are effective tools for teaching basic robotics and programming concepts at secondary and tertiary education levels (De Lima et al., 2018; Nur et al., 2022; Selatan et al., 2026).

Hands-on learning through programming and configuring line follower robots offers numerous educational benefits. Research by (Barak & Zadok, 2009) shows that engaging in robotics projects enhances students' understanding of science, technology, and problem-solving concepts. (Abdillah & Puspitasari, 2025; Joseph et al., n.d.; West, 2012) also noted that robotics education effectively improves students' academic performance in science. Participation in these practical robotics activities enables students to develop essential 21st-century skills, including collaboration, communication, creativity, and critical thinking.

Activities involving the configuration and programming of line follower robots require students to apply step-by-step reasoning and decision-making processes, thereby supporting the development of logical thinking in practical technological contexts. (Dewi et al., 2026; Wuandari et al., 2025).

However, a review of national and international literature reveals a significant research and implementation gap. Although educational robotics has been widely studied in general education and university settings, limited research has examined its application as a structured approach to developing logical thinking skills in vocational high school contexts. Most robotics education studies focus on general secondary schools or higher education contexts, often emphasizing competition-based activities rather than structured logical thinking development (Benitti, 2012; Budiyanto et al., 2022; Eguchi, 2014). In Indonesia, robotics initiatives in SMKs are still limited, fragmented, and frequently extracurricular without a clear pedagogical framework linked to cognitive skill development (Rafidiyah & Kailani, 2020; Wahyuni et al., 2021; Yusadinata et al., 2021). Moreover, few community service programs explicitly position robotics training as a means to strengthen logical thinking as a core competency for vocational students, particularly within schools with limited STEM extracurricular options.

This community service initiative addresses this gap by introducing a structured robotics training program centered on configuring and programming line follower robots as a medium for logical thinking development. The novelty of the program lies in three main aspects. First, it adopts a problem-based and logic-oriented learning approach, explicitly connecting mathematical logic concepts such as conjunction, disjunction, implication, and negation to programming decisions and robot behavior. Second, the training format emphasizes hands-on system configuration, integrating basic electronics, sensor calibration, and algorithmic reasoning rather than relying solely on preassembled kits. Third, the program is implemented within the specific context of an SMK with a Computer and Network Engineering (TKJ) major, ensuring alignment with students' prior knowledge while extending it toward applied robotics.

This community service program contributes to the development of a practice-based STEM learning model that uses educational robotics to support logical thinking development in vocational students. By fostering logical thinking and technological competence, the program supports the school's capacity to deliver quality STEM-oriented education, thereby strengthening institutional readiness to meet future workforce demands. At a broader level, the initiative contributes to SDG 4 by enhancing the quality and relevance of vocational education and to SDG 8 by equipping students with skills that improve employability in technology-driven sectors.

The relevance of this initiative is particularly evident at SMK Muhammadiyah 9 Wagir, a vocational school with a Computer and Network Engineering (Known as "TKJ" in Indonesian Acronym) major but limited technology-oriented extracurricular activities. Currently, the school mainly offers physical extracurricular programs such as Airsoft and Futsal, with no activities specifically designed to develop students' logical thinking skills. In this context, introducing robotics through line follower robot programming provides a strategic opportunity to expand STEM learning experiences and support logical thinking development among students. Therefore, this initiative not only benefits the students but also contributes to broader educational and societal advancement.

Configuring a line follower robot requires an understanding of computer logic derived from basic principles of mathematical logic. In practice, concepts such as conditional reasoning and logical operators are translated into programming instructions that determine how the robot responds to sensor inputs, for example deciding whether the robot should move forward, turn left, or turn right when a line is detected. These include disjunction, conjunction, implication, bi-implication, negation, and other logical operators. Robotics education requires a blend of knowledge in mathematics, electronics, and informatics subjects that align closely with the TKJ major at SMK Muhammadiyah 9 Wagir. While students have already been introduced to computing, informatics, and related mathematics, they would benefit from additional exposure to basic electronics and advanced mathematical logic in order to fully grasp how to configure and control line follower robots.

In summary, this community service initiative responds to an urgent educational problem: the gap between vocational education outcomes and the cognitive-technological skills demanded by the modern workforce. By leveraging line follower robot programming as a medium for logical thinking development, the program offers a novel, context-sensitive approach to strengthening STEM competencies among SMK students. This community service program aims to strengthen vocational students' logical thinking skills through STEM-based learning using line follower robot programming. The program contributes an applied robotics learning approach that supports the development of logical reasoning and technological competencies in vocational education. Its contributions are relevant at the institutional, national, and global levels, aligning vocational education with the broader agenda of sustainable development and future-ready human capital.

METHOD

This activity was conducted over a one-month period. The training program was divided into several key stages, as illustrated in Figure 1, which presents the community service flowchart.

- **Step One:** A Focus Group Discussion (FGD) was held with SMK Muhammadiyah 9 Wagir to identify the school's challenges and needs in the field of technology.
- **Step Two:** Development of instructional materials for the line follower robot training. The materials were designed based on STEM learning principles and adapted to the competencies of the Computer and Network Engineering (TKJ) curriculum. The development process involved reviewing relevant robotics learning resources, preparing step-by-step programming and configuration instructions, and adjusting the level of difficulty to match students' prior knowledge.
- **Step Three:** Implementation of the training session.
- **Step Four:** Evaluate Program Outcome

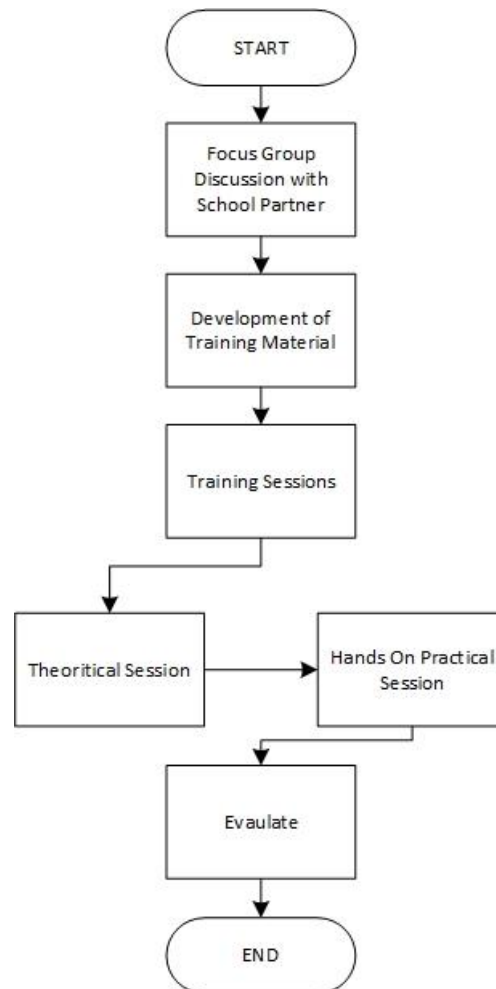


Figure 1. Community Service Flowchart

These steps were based on the premise that robotics technology is advancing rapidly in today's high-tech era, requiring both innovation and creativity to design robots that meet users' evolving needs. In the first step, the school's challenges and requirements were discussed during the FGD. As a result of this discussion, the community service team proposed a training program centered on the line follower robot.

The second step involved developing a structured training module and outlining the materials to be delivered. The third step was the actual implementation of the training. All three stages were carried out within a one-month period, with each stage offering targeted solutions to address the specific issues and needs identified by the partner school.

The logical thinking training activity through the use of line follower robots was conducted in a one-day workshop, held from 08:00 to 12:00 WIB at SMK Muhammadiyah 9 Wagir. A total of 17 students participated in the activity. The participants consisted of all students from one class in the Computer and Network Engineering (TKJ) major, selected using a whole-class participation approach to ensure that the training involved the entire group of learners. The training was conducted in a classroom setting. The training followed a three-stage method: theoretical instruction, hands-on practice, and evaluation.

The purpose of the theoretical session was to strengthen students' understanding of the foundational concepts behind line follower robots, including how they work and the functions of their components. Through hands-on practice, students gained direct experience in configuring and programming the robots, allowing them to apply the theoretical knowledge they had acquired. The final component of the training was an evaluation phase, conducted through performance-based assessments.

The evaluation criteria consisted of the following:

1. Theoretical Knowledge: Assessing students' comprehension of the material covered.

follower robot. This program not only supports technology-based learning but also enhances students' logical thinking skills. Furthermore, the line follower robot is commonly used in various competitions, offering students future opportunities to participate at regional or national levels (Nur et al., 2022; Siswanto & Triono Sigit, 2019). Figure 3 presents documentation of the Focus Group Discussion conducted with school representatives, which served as the basis for program design.



Figure 3. Focus Group Discussion with the School Representatives

The school expressed a strong interest in expanding students' access to technology- and STEM-oriented learning activities. In response to these needs, the community service team proposed a line follower robot training program designed to introduce robotics concepts while simultaneously strengthening students' logical thinking skills. The selection of a line follower robot was also motivated by its relevance to robotics competitions, providing students with potential pathways for future participation at regional or national levels.

Implementation of the Training Program

Based on the FGD outcomes, the training program was implemented in two sequential stages: a theoretical session followed by a hands-on practical session. The first stage focused on conceptual understanding. Students received an introduction to line follower robots, including definitions, key components, working principles, and real-world applications. The material was delivered using a structured PowerPoint presentation to ensure clarity and accessibility. Figure 4 illustrates the theoretical training session, during which foundational concepts of line follower robots were explained.



Figure 4. Training Session: Theoretical Explanation of Line Follower Robots

The second stage emphasized experiential learning. Students directly engaged in programming a line follower robot with a specific task: navigating from a starting point to a finishing point along a predefined track. Two robot kits and two track layouts were used to facilitate active participation and collaborative learning. Due to limited equipment availability, students worked in small groups, which also encouraged collaborative problem-solving and discussion during the robot configuration and testing process. Figure 5 shows the practical training session in which students programmed and tested the line follower robots.



Figure 5. Practical Training Session: Programming the Line Follower Robot

Evaluation Results and Program Outcomes

Prior to the training, brief interviews were conducted with all participating students to identify their initial understanding of robotics concepts. The results indicated that none of the students had prior knowledge of line follower robots, and their perceptions of robotics were largely influenced by media portrayals of highly advanced robotic systems. After completing both stages of the training, a clear shift in students' perceptions and interest was observed. To present the evaluation results systematically, Table 1 summarizes the key indicators of program outcomes.

Table 1. Program Outcomes

Indicators	Result
Number of Participants	17 Students
Prior knowledge of Line Follower Robots	0 Student (0%)
Students expressing interest in further learning robotics	13 Students (76%)
Task completion success (start to finish navigation)	17 Students (100%)

The results indicate that all participants successfully completed the assigned programming task, demonstrating their ability to apply basic logical reasoning and programming concepts. Although guidance was provided by lecturers and university students, the students were able to operate the robots independently by the end of the session. Based on these findings, the indicators of program success were defined as: (1) Increased student interest in robotics and STEM learning, (2) Successful completion of the assigned robotic task, and (3) Active participation during both theoretical and practical sessions. All three indicators were achieved during the program implementation. Figure 6 presents a group photo taken at the conclusion of the training session, documenting participant engagement and program completion.



Figure 6. Group Photo at the Conclusion of the Training Session

Discussion

The primary objective of this community service program was to enhance students' logical thinking skills through hands-on robotics learning while increasing their exposure to STEM-related activities. The results demonstrate that the line follower robot training effectively met these objectives, particularly in a vocational school context with limited prior robotics exposure.

The results showed an increase in students' interest in robotics, with 76% of participants expressing willingness to learn more about robotics after the training. This finding is consistent with previous studies reporting that hands-on robotics activities can enhance students' motivation and engagement in STEM learning (Barak & Zadok, 2007; Benitti, 2012; Ching & Hsu, 2023; Koray et al., 2023). By interacting directly with robotic systems, students were able to connect abstract logical concepts such as conditional statements and decision-making processes to tangible outcomes, reinforcing their understanding through practice.

The 100% task completion rate indicates that the students were able to successfully follow the programming instructions and complete the assigned navigation task. This result suggests that clear instructional guidance, scaffolding, and hands-on activities can support students in completing basic robotics programming tasks. This finding is consistent with (Eguchi, 2014; Rahman, 2021), who noted that introductory robotics platforms are particularly effective for developing problem-solving and logical reasoning skills among novice learners. In the context of vocational education, such experiences are crucial for preparing students to work with automated and cyber-physical systems commonly found in modern industries. Furthermore, the results highlight the importance of contextual relevance. By aligning the robotics training with the students' TKJ major, the program enabled learners to build upon their existing knowledge of computing and programming while extending it toward applied electronics and system control. This integrated approach supports earlier findings that interdisciplinary STEM activities are more effective than isolated subject instruction in vocational settings (Carney, 2022; UNESCO, 2021).

Several limitations of the program should be acknowledged. The small sample size ($n = 17$) and the focus on a single institution limit the generalizability of the findings. Additionally, the absence of a control group and the short duration of the intervention make it difficult to assess long-term impacts on logical thinking development. These limitations are common in community service-based educational interventions and have been reported in similar studies (Benitti, 2012; Dogara et al., 2019; Ulaini & Fitriasia, 2025)

Future programs could address these limitations by involving larger and more diverse participant groups, incorporating control or comparison conditions, and implementing longitudinal designs to assess sustained learning outcomes. Further exploration of more complex robotic tasks or different types of robots may also provide deeper insights into the most effective strategies for fostering logical thinking and sustained STEM interest among vocational students. Additionally, integrating robotics-based learning with instructional models such as blended learning or flipped classrooms could enhance scalability and alignment with national vocational competency standards.

Overall, this community service program demonstrates that robotics-based training using line follower robots is a feasible and effective approach for strengthening logical thinking and promoting STEM engagement among SMK students, contributing meaningfully to the broader goals of quality vocational education and workforce readiness.

CONCLUSION

Through this activity, students at SMK Muhammadiyah 9 Wagir were introduced to robotics technology in a fun and engaging way, helping them to develop their logical thinking and imagination. The fact that all students were able to successfully program the line follower robot indicates significant progress in their logical reasoning skills. To further enhance these skills, it is recommended that future activities present students with more challenging missions, encouraging deeper thinking and problem-solving. This initiative also demonstrates how vocational schools can adopt logical thinking and STEM-based learning as part of their educational approach. As a follow-up outcome, students are now better equipped to participate in line follower robot competitions, which can provide additional motivation and real-world experience in the field of robotics.

AUTHORS CONTRIBUTIONS

YSAG conceptualized the community service program, designed the STEM-based learning framework, coordinated the overall implementation, and led the manuscript writing and revision. SS contributed to the development of instructional materials, including robotics modules and programming activities, and was actively involved in conducting the training sessions. AR supported the design of learning activities and assisted in guiding students during hands-on robotics practice. SAB contributed to the evaluation design and data analysis, particularly in assessing students' logical thinking development and engagement. WSP assisted in technical implementation, including robot configuration and programming support during the training sessions. BA contributed to data collection, documentation of activities, and administrative coordination with the school partner. All authors reviewed and approved the final version of the manuscript.

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