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Integrating STEM into Middle School Science through Smart Agriculture Projects

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Abstract The STEM Center for Teaching and Learning at Parahyangan Catholic University, in collaboration with Ruang Bergerak, organized a community outreach program as part of its *Tridharma* commitment. The program included seminars and hands-on training for science teachers from the MGMP (Subject Teachers Forum) in Salatiga. The goal was to introduce project-based learning (PBL) methods using a STEM (Science, Technology, Engineering, and Mathematics) approach within the context of smart agriculture. This initiative aimed to help teachers foster essential 21st-century skills—such as problem-solving, critical thinking, and collaboration—that had noticeably declined during the pandemic. This program was designed to support teachers in implementing integrated, project-based learning that not only crosses disciplinary boundaries but also ties directly to measurable learning outcomes. Teachers were encouraged to connect the projects to real-world contexts, making assessments more meaningful and relevant to each subject area. Additionally, the smart agriculture project served as a practical application of P5 (*Proyek Penguatan Profil Pelajar Pancasila*) under Indonesia's *Merdeka* Curriculum. Teachers were given the flexibility to adapt the prototype projects for further development in their own schools, aligning with each school's unique goals and agreements. Over the course of two days, participating teachers learned how to design and execute contextual, problem-based STEM projects. They gained hands-on experience with technologies like Arduino and agricultural sensors. The program consisted of two main phases, the first involved expert-led workshops, and the second focused on collaborative project design based on local agricultural challenges. Despite the limited time, the program successfully fostered collaboration among teachers and expanded their understanding of how integrated, STEM-based learning can support both academic goals and character development through P5.

1. INTRODUCTION

Classroom learning activities are a vital part of the education system's effort to equip students with the skills to read, analyze, identify problems, and develop solutions. However, the lingering impact of the pandemic on education is still being felt. The shift to online learning created significant challenges, particularly due to limited interaction between teachers and students. Many students struggled to fully grasp the material, especially when learning independently, as access to learning tools and resources was often limited (Angraini et al., 2021). The constraints of online platforms also restricted the variety of teaching methods that could be used, ultimately narrowing the scope of learning activities. As a result, studies have reported a noticeable decline in students' problem-solving abilities, critical thinking, and collaboration skills (Muzana et al., 2021; Pratama, 2021). In response, teachers must

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design engaging learning experiences that reignite students' motivation and help rebuild these essential skills. Beyond academic improvement, these learning activities should also be contextual, meaningful, and infused with humanitarian values—allowing students to gain hands-on, real-world experience. One effective approach that meets these criteria is the project-based learning (PBL) model. PBL not only supports the development of problem-solving and critical thinking but also grounds learning in real-life contexts and fosters empathy and social responsibility (Fredagsvik, 2021).

Project-based learning (PBL) is an instructional model that emphasizes both the process and the outcome of learning, with students developing prototypes as tangible solutions to real-world problems identified during the learning process. Through PBL, students are encouraged to design solutions to contextual problems provided by the teacher, implement those solutions in the form of prototypes, explain their problem-solving processes, and, in doing so, strengthen their problem-solving and collaboration skills (Winarni et al., 2022). PBL also fosters essential interpersonal skills by requiring students to engage in group discussions, navigate differing perspectives, work toward consensus, and develop solutions that benefit the group as a whole rather than relying solely on individual viewpoints. One effective framework for supporting project-based learning is the STEM (Science, Technology, Engineering, and Mathematics) approach (Gale et al., 2020). STEM-based learning encourages students to routinely practice problem identification, solution planning, and the application of interdisciplinary knowledge to real-life challenges. This approach not only sharpens students' critical thinking but also helps them connect academic concepts to practical situations. Additionally, STEM-based projects naturally integrate multiple disciplines, providing opportunities for cross-subject collaboration. Teachers can work together to design projects that align with several subject areas, allowing the final student outcomes, whether prototypes, reports, or presentations, to serve as assessments across those integrated subjects. This collaborative approach also helps teachers share the workload while producing meaningful, multidimensional learning experiences for students (Badriyah et al., 2021; Hariyanto et al., 2022; Ouyang, 2022).

As part of its efforts to promote integrated learning, the STEM Center for Teaching and Learning at Parahyangan Catholic University organized seminars and training tailored to meet teachers' needs. These activities specifically targeted MGMP science teachers across the city of Salatiga. The two-day program focused on the theme of STEM-integrated learning, with an emphasis on designing STEM-based projects for classroom implementation. To ensure relevance and practicality, the projects were designed around issues familiar to both teachers and students in their local environment. The chosen context for this training was the agricultural sector. By the end of the seminar and workshop, participants were expected to produce a functional smart agriculture prototype as a tangible outcome of the learning process (Halawa, 2024).

In addition to members of the STEM Center for Teaching and Learning at Parahyangan Catholic University, experts from Ruang Bergerak also joined the team to support the program. While teachers in Salatiga generally had sufficient access to teaching and learning facilities, they faced significant challenges when it came to implementing integrated learning strategies. Recognizing this gap, the seminars and training sessions were designed to offer fresh perspectives, practical strategies, and innovative ideas to help teachers successfully adopt integrated, project-based STEM learning in their classrooms.

2. METHOD

The community service program organized by the STEM Center for Teaching and Learning at Parahyangan Catholic University, in collaboration with Ruang Bergerak, was conducted in the form of seminars and hands-on training for MGMP science teachers across Salatiga. The program was implemented at two locations using the same approach, SMP Negeri 1 Salatiga, involving MGMP IPA teachers, and SMP Kristen 2 Salatiga, involving teachers from that school. However, this article specifically focuses on the activities carried out at SMP Negeri 1 Salatiga with MGMP IPA teachers to provide a more in-depth discussion. The program was delivered in two sessions, the first day consisted of a seminar, and the second day focused on hands-on STEM project development. During the seminar on day one, topics included student-centered learning, integrated learning, and an introduction to the tools and materials that would be used in the workshop. The session also outlined the procedures for the following day's activities. Additionally, teachers were encouraged to identify real-world problems, particularly related to agriculture, and brainstorm potential solutions to be developed during the hands-on session. On the second day, teachers participated in group-based STEM project activities. The participating junior high school science teachers were divided into small groups of 4 to 5 members. Each group began by discussing and selecting a project theme along with a relevant problem to address. Once a consensus was reached, group members worked collaboratively to design and develop a solution, ultimately presenting it as a STEM-based project prototype. This process ensured that the available tools and materials were used effectively and efficiently by all participants.

During the STEM project activities focused on agriculture, we guided teachers in using the provided materials—particularly electronic components that required programming, such as Arduino boards connected to capacitive soil sensors. Arduino was selected as a key tool due to its accessibility, affordability, and flexible programming capabilities, making it well-suited for educational projects.

The teachers followed the following structured, three-step process in developing their STEM projects.

1. Identifying real-world agricultural problems

2. Developing feasible solutions to address those problems
3. Designing prototypes or working models to represent both the problem and the proposed solution in a tangible, practical way

As the final step, teachers were asked to present their completed projects to the other groups. This sharing session provided an opportunity for participants to exchange ideas, offer constructive feedback, and explore how they could adapt these projects into their own teaching practices. Following the presentations, teachers engaged in reflective discussions—not only evaluating the projects themselves but also exploring how the projects could be integrated into science lessons and connected with other subject areas. They were encouraged to align the projects with relevant learning objectives and topics within the curriculum. In the final phase of the training, teachers were guided to develop their own assessment rubrics tailored to their specific projects. This approach allowed for diverse, flexible assessment methods rather than relying on a standardized rubric for all projects. Overall, this training successfully equipped teachers with the skills to implement project-based learning that aligns with one of the core components of the *Merdeka* Curriculum, the P5 Project.

3. RESULT AND DISCUSSION

The seminar and training sessions were conducted over two days, starting at 1:00 PM after the teachers had finished their regular teaching duties at their respective schools. Participants included MGMP science teachers from across Salatiga. The entire program took place in the hall of SMP Negeri 1 Salatiga on consecutive days. The first day began with an introduction to the program, including the goals and mission of the STEM Center for Teaching and Learning at Parahyangan Catholic University and Ruang Bergerak. To help participants re-energize after a full day of teaching, the session included lunch and light games designed to boost engagement and restore enthusiasm (Figure 1 and Figure 2). The first-day seminar featured two main topics, student-centered learning and integrated learning (Figure 3). The speakers delivered the material while the teachers listened, took notes, and engaged with the key points presented.

The topics of student-centered and integrated learning were crucial, as they served as the foundation for the hands-on training session scheduled for the following day. Another key consideration was the need to use time efficiently, since the program was held after regular school hours, leaving participants with a limited window for engagement. At the end of the first day, a question-and-answer session was held, allowing teachers to interact directly with the experts, supported by members of our team. Before concluding, participants were reminded to return to the same venue the next day for the follow-up session, which would focus on practical training in implementing integrated STEM project-based learning.

The second day focused on hands-on training in implementing integrated STEM project-based learning through the development of a smart agriculture concept. This session utilized tools and materials provided by the community service team. Some of the materials included cardboard, recycled bottles, adhesives, cutting tools, coloring supplies, and various electronic components such as Arduino UNO R3 with a USB cable, a 5V relay module, a capacitive soil moisture sensor, an LCD I2C 1602 display, a breadboard (830 points), and 20 cm male-to-female jumper wires (Figure 4). The decision to focus on a smart agriculture project was intentional, as Salatiga is a city where a significant portion of the population

Figure 1 . Refreshment activities before the seminar

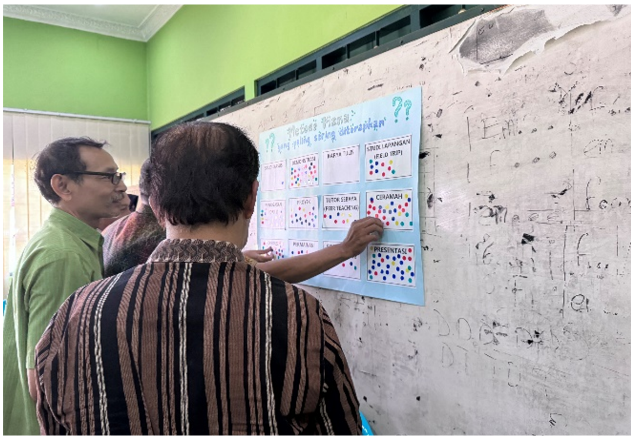

Figure 2 . Choosing the learning methods usually used but the teachers in class

Figure 3 . The delivery of the materials by the experts

works in agriculture. Naturally, this sector faces a variety of challenges, ranging from simple to complex (Indriani, 2020; Singh & Ahmed, 2021). This context made the project highly relevant and meaningful for the participating teachers.

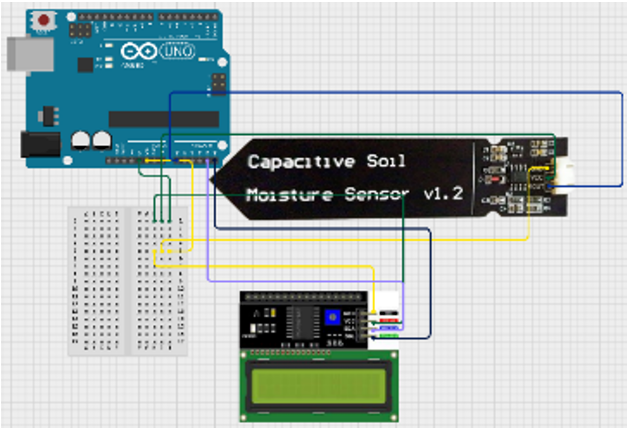

Figure 4 . Smart agriculture circuit

Figure 5 . Discussion process with the experts

The central challenge addressed in the smart agriculture project was how to develop a system that could integrate various farming processes—such as automated watering, fertilization, plant growth monitoring, and even harvest timing. To achieve this, teachers were guided to design the layout, consider the environmental conditions, and determine the specific agricultural focus for their prototype. For example, one group designed a smart agriculture system for rice farming. Their prototype simulated a system capable of detecting factors related to rice plant diseases, identifying common pests, and regularly measuring soil pH. To further optimize the rice cultivation process, the group also proposed integrating an internet-based monitoring device. This system was designed to collect and manage data over different growth cycles, enabling farmers to respond quickly to emerging problems or environmental changes (Rachmawati et al., 2022). Additionally, the data analysis features incorporated into the prototype were intended to help farmers monitor productivity and make more accurate forecasts. This capability aimed to enhance the efficiency of agricultural production and reduce the risk of crop failure. Through this project-based learning process, teachers collaborated to develop solutions based on real-life, contextual problems from their surroundings. The result was a functional prototype that addressed specific agricultural challenges (Figure 5) (Michaluk et al., 2017; Rahayu et al., 2022).

At the end of the session, the teachers presented the results of their prototypes, along with how their projects could be integrated into the subjects they taught. Since the participants in this session were all science teachers, the problems were primarily approached from the perspectives of physics, biology, and chemistry. To broaden their understanding of interdisciplinary integration, we introduced additional perspectives from mathematics, such as plane and spatial geometry, similarity, scale calculation, and geometric transformations. Beyond math and science, the project also had the potential to be integrated into social studies, for example, by exploring topics like regional layout, agricultural land use, or the historical and cultural development of farming communities. Similarly, connections could be made with the arts through aspects like color mixing, aesthetic design of structures, and other creative elements relevant to middle school art curricula.

This activity served as one of the initiatives to support teachers in implementing integrated project-based learning. Beyond subject integration, teachers were also encouraged to present the learning outcomes in a contextual manner, ensuring that assessments could be aligned objectively with the learning goals of each subject area. Additionally, this project-based approach functioned as a practical application of the *Proyek Penguatan Profil Pelajar Pancasila* (P5) within the *Merdeka* Curriculum. The prototypes developed during the training were designed to be adaptable, allowing teachers to further refine and implement them in their respective schools according to each school's unique needs and agreements.

4. CONCLUSION

The seminars and hands-on training provided teachers with valuable opportunities to exchange ideas, engage in discussions, collaborate, solve problems, and participate in meaningful learning experiences. A key takeaway from this program was that teachers were able to identify real-world, contextual problems within their communities, develop interdisciplinary solutions, and present those solutions in the form of integrated STEM projects applicable to everyday life.

Importantly, teachers were actively involved in every stage of the process, allowing them not only to recognize problems but also to become problem solvers. This hands-on involvement fostered deeper understanding and ownership of the learning model. The program offered several notable strengths. The materials and topics presented were highly relevant to the teachers' daily experiences and teaching environments. Teachers gained practical skills in identifying contextual problems, designing solutions, and developing functional prototypes. They also learned how to integrate these projects into multiple subject areas and create appropriate assessment rubrics aligned with targeted learning outcomes.

Despite these successes, the program did face certain limitations. The primary challenge was the limited time available, which constrained the depth of discussions—particularly around how to fully connect problem-based STEM projects with the goals of the *Proyek Penguatan Profil Pelajar Pancasila* (P5) within the *Merdeka* Curriculum.

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CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest related to this manuscript.

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