

## Habituating STEM Integration Through Learning Communities: a Development Study in Banjarmasin, Indonesia

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### Abstract

STEM education trains students to solve complex problems by integrating knowledge of science, technology, engineering, and mathematics into a learning experience. While awareness of STEM's importance is growing among educators in Indonesia, consistent integration into Science instruction remains challenging. This development study investigates the effectiveness of a STEM-Learning Community (STEM-LC) model in habituating STEM practices among Indonesian science teachers. Utilizing the Plomp development model, the study involved ten schools across two implementation cycles. The STEM-LC model comprised five structured phases: (1) forming a learning community, (2) learning about STEM, (3) preparing lesson plans, (4) conducting learning phases one and two, and (5) reflection. The model's practicality was assessed based on the execution and fluidity of each stage, teachers' responses to the STEM-LC model, their understanding of STEM, and students' feedback on STEM learning. Data were collected through observation sheets and questionnaires, then analyzed qualitatively and descriptively. Findings revealed that the STEM-LC habituation model was implemented effectively, achieving a score of 91, with the 'social system' aspect rated highest. Notably, 96.6% of teachers successfully implemented STEM learning, and students responded positively, scoring 72.5. Students expressed enjoyment in STEM activities and a desire for continued engagement. Despite initial unfamiliarity with STEM, the structured phases of the STEM-LC facilitated more straightforward implementation. These results demonstrate that the STEM-LC model is a viable and effective strategy for developing sustained STEM integration habits in Science education and holds potential for broader implementation across Indonesian schools.

**Keywords:** habituation model, learning community, learning increase, STEM, project based learning



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## 1. Introduction

The increasing complexity of life in the era of globalization has led to more intricate challenges faced by humanity. STEM education (Science, Technology, Engineering, and Mathematics) is designed to equip students with the skills necessary to address complex problems by integrating their knowledge of science and mathematics. The

primary goal of STEM education is to develop students' STEM literacy, enabling them to become future experts in related fields (Nilvo, 2023). STEM literacy refers to the ability to apply concepts from science, technology, engineering, and mathematics to understand complex problems and collaboratively innovate solutions to these challenges (Jackson et al., 2021).

The STEM framework is based on the Case-Based Method (CBM) and Team-Based Project (TBP) models. Although both are problem-based, what distinguishes CBM and TBP from STEM is that solutions in STEM are developed by integrating aspects of science, technology, engineering, and mathematics. Through STEM, students learn to solve problems while seeking solutions through project-based learning that combines these four aspects. Integrating STEM elements into CBM and TBP improves the quality of learning and makes STEM goals more achievable (Afriana et al., 2016; Lutfi et al., 2018). Research by Winarti et al (2023) has provided scientific evidence regarding the effectiveness of CBM and TBP in improving the quality of learning, such as fostering positive and meaningful communication between teachers and students, improving high-level thinking skills (HOTS), critical thinking skills, and collaboration skills. Integrating STEM aspects into learning increases the effectiveness of the CBM and TBP models (Annisa et al., 2022). Various studies have shown that STEM has a positive effect on scientific knowledge and literacy (Tuong et al., 2023), problem-solving skills (Khoiri, 2019; Zakiyah et al., 2021), conceptual understanding (Sarioğlan & Özkaya, 2023), creativity, and metacognition (Astawan et al., 2023; Wang et al., 2022; Winarti et al., 2019). This is because STEM encourages students to actively think and engage in fun, practical activities, rather than just listening to lectures. Engaging students in fun learning activities improves retention, motivation, and critical thinking skills (Magdalena, 2021; Russo, 2020; Syahmani et al., 2022; Winarti, et al., 2019).

In addition to the increasingly complex problems, the impact of globalization is believed to eliminate 85 million jobs by 2025

while creating 97 million new jobs, most of which will be related to STEM. In European countries, STEM is the primary driver of new job growth, with 34% of jobs filled by positions involving STEM. This situation has encouraged many countries to integrate STEM into their curriculum. For example, China established an intensive STEM education and training center in 2016. Malaysia has allocated a curriculum ratio of 60:40% for science and engineering in STEM education. Singapore implements STEM at all levels of education with a predetermined curriculum (Mwembe et al., 2022).

Indonesia has also begun implementing STEM through teacher training programs. However, the development of STEM education in the country has been relatively slow. Research indicates that teachers face several challenges in implementing STEM, including insufficient pedagogical skills for teaching science, a lack of investigative tools (Nguyen et al., 2024), and limited knowledge of STEM concepts (Suhirman & Prayogi, 2023). Teachers often struggle to connect real-world problems to science subjects and are further hindered by time constraints and limited parental support. Moreover, the training methods provided are usually misaligned with the infrastructure and contextual realities of Indonesian schools (Plomp, 2020).

Given these challenges, a critical question emerges is how can Indonesian science teachers be supported to sustainably integrate STEM practices into their teaching despite limited familiarity with STEM pedagogy, inadequate infrastructure, and isolated professional development experiences.

Traditional one-time training workshops have proven insufficient for developing lasting pedagogical change. Teachers require

ongoing support, collaborative learning environments, and opportunities to practice STEM implementation in an authentic classroom context. This raises a secondary question is what model of professional development can effectively habituate STEM practices among teachers while addressing the contextual realities of Indonesian schools.

This study aims to promote the implementation of STEM in science education in Indonesian schools through the introduction of the STEM-Learning Community (STEM-LC), a habituation model structured around the following stages: (1) Formation of a Learning Community; (2) STEM Workshop; (3) Development of Lesson Plans; (4) Implementation of STEM-Based Instruction; and (5) Reflection. It is expected that this study will produce a practical and effective model for habituating STEM implementation, thereby accelerating the advancement of STEM education in Indonesia.

The STEM-LC model proposed in this study is grounded in several interconnected theoretical frameworks and empirical findings that support its relevance as a solution. Based on Community of Practice Theory by [Wenger \(1998\)](#), learning communities function as communities of practice where members engage in collective learning through shared experiences, mutual support, and collaborative problem-solving. Research by [Vangrieken et al \(2015\)](#) found that teacher learning communities significantly improve instructional practices and professional identity.

The STEM-LC model operationalizes this theory by creating structured spaces where teachers collaboratively learn, plan, implement, and reflect on STEM practices. The habituation of STEM in this study was implemented by applying [Dewey's Theory](#)

[\(1938\)](#) of experiential learning, which emphasizes that habits are formed through repeated practice within a supportive environment. The five-phase STEM-LC structure provides iterative opportunities for teachers to engage with STEM concepts, practice implementation, receive feedback, and refine their approaches creating conditions for sustained behavioral change rather than superficial awareness.

Regarding the collaborative approach in STEM-LC design, multiple studies have validated the effectiveness of this approach, including [Borko, et al, \(2014\)](#) who stated that collaborative professional learning communities significantly improved teachers' STEM instructional quality and student outcomes; [Margot and Kettler \(2019\)](#) who found that collaboration and ongoing support as critical factors for successful STEM integration; and research by [Akaygun and Aslan-Tutak \(2016\)](#) who demonstrated that collaborative approaches help teachers develop more integrated STEM conceptions.

Unlike conventional training programs that treat teachers as passive recipients of knowledge, the STEM-LC positions teachers as active agents of change within supportive professional networks. This approach aligns with findings from [So et al. \(2020\)](#) and [Lehman et al. \(2014\)](#), who emphasize that meaningful STEM integration requires sustained collaboration, shared expertise, and institutional support systems.

Therefore, this study investigates whether the STEM-LC model can serve as an effective habituation mechanism for STEM integration in Indonesian science education, addressing both the pedagogical and systemic barriers that have hindered previous implementation efforts.

## 2. Method

This study applies Design-based Research (DBR) with the Plomp model. DBR is a study that aims to design, develop, and evaluate a program (J Akker et al.,

2010). In this study, the program developed was STEM-LC, which was piloted in science instruction at the junior secondary school (SMP) level. The research procedures are presented in Figure 1.

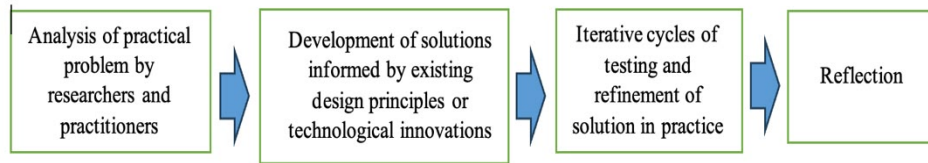


Figure 1 The Steps of DBR According to Plomp

The practicality of STEM-LC implementation was evaluated based on the execution of three aspects of the model: syntax, principle of reaction, and social system (Joyce et al., 2014). The syntax is a sequence or flow of STEM-LC activities, the principle of reaction describes the expected interaction and responses between all parties in STEM-LC activities, and the social system is the applicable norm and the role of all parties in STEM-LC.

The STEM-LC implementation was carried out in selected schools using purposive sampling. The sample consisted of 10 public junior high schools in Banjarmasin, 40 teachers of science, mathematics, and IT from these schools, as well as 120 students from 4 schools chosen as the pilot sites for STEM-LC implementation. The following is a hypothetical model of STEM-LC.

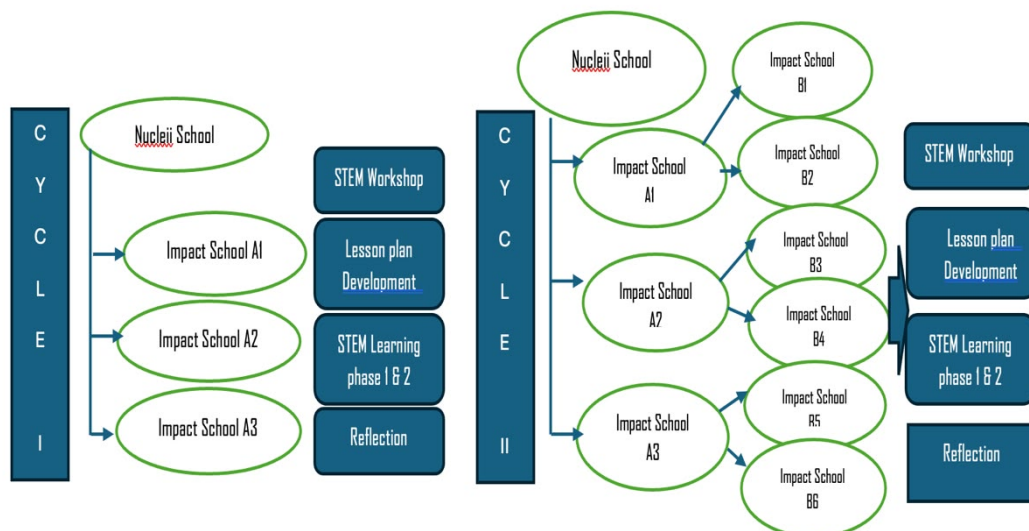


Figure 2. The Framework of the STEM-LC Model

Nucleii School (NS) is a core school that coordinates all STEM-LC activities. In this study, Nucleii School (NS) refers to the State Junior High School (SMPN) 19 Banjarmasin. Three schools: Impact School A (IS-A), namely SMPN 8 (IS A1), SMPN 16 (IS A2), and SMPN 23 (IS A3), were

formed in the first cycle. These four schools then served as STEM disseminators to six other schools, referred to as Impact Schools B (IS B) in the second cycle, namely: SMPN 7, SMPN 10, SMPN 11, SMPN 22, SMPN 16, SMPN 30. The formation of a Learning

Community (LC) was carried out in this second cycle.

The implementation of STEM-LC activities in this study was conducted over a period of 5 months, consisting of 2 project-based STEM lessons in Cycle 1 and 6 lessons in Cycle 2, covering four different

STEM project topics. The Cycle 1 lessons were conducted at Nucleii School, while the Cycle 2 lessons took place at schools selected by each Learning Community (LC). The formation of STEM-LC and the students' project is presented in Table 1 below.

**Table 1. The Formation of STEM-LC and Students' STEM Project**

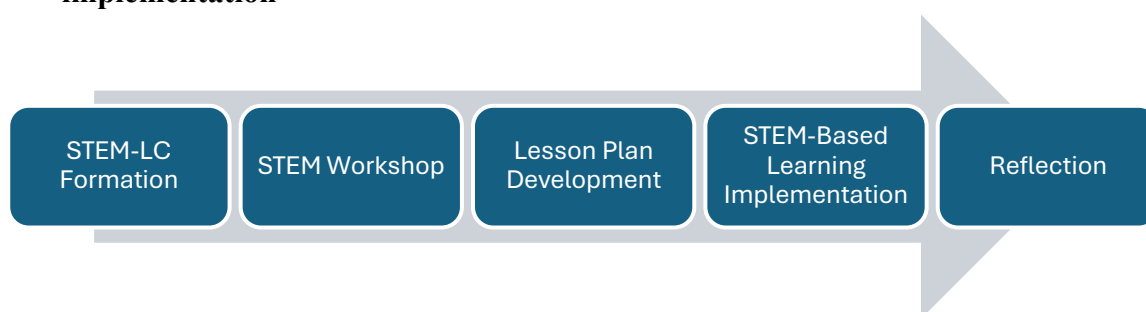
| Cycle | LC | Schools                 | STEM Project                                     |
|-------|----|-------------------------|--------------------------------------------------|
| I     |    | NS; IS A1; IS A2; IS A3 | The construction of a simple water filter        |
| II    | 1  | NS, IS A1; IS B1; IS B2 | The construction of a simple Automatic Water tap |
| II    | 2  | NS, IS A2; IS B3; IS B4 | The construction of a simple Water purifier      |
| II    | 3  | NS, IS A3; IS B5; IS B6 | The construction of Biopores                     |

The data was collected using instruments of practicality, learning observation sheets, and interviews adapted from Winarti (2019), as well as teacher understanding instruments for STEM and Attitude Toward STEM (AT-STEM), adapted from Mahoney (2010). Furthermore, the data were analyzed using a qualitative descriptive method.

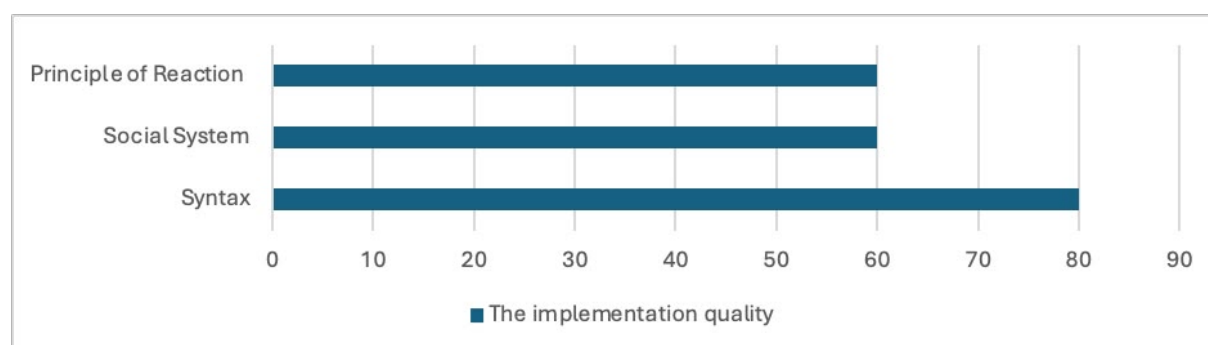
The practicality of STEM-LC implementation is crucial, as it determines how easily this model can be applied. The practicality indicator is assessed based on the quality of the implementation of the STEM-LC aspects, such as syntax, principle of reaction, and social system. The syntax of STEM-LC consists of the following stages, as shown in Figure 3, and the practicality of STEM-LC implementation in the first cycle is presented in Figure 4.

### 3. Result and Discussion

#### a. The practicality of STEM-LC implementation



**Figure 3. The Syntax of STEM-LC**



**Figure 4. The Practicality of STEM-LC Implementation on Cycle 1**

The data presented in Figure 4 indicate that the implementation of STEM-based learning in Cycle 1 was moderately successful, with an average score of 66.7. The moderate success in Cycle 1 reveals essential insights into the factors influencing STEM-LC adoption. The disparity between syntax quality (very good) and the other aspects (quite good) suggests that procedural understanding develops more quickly than relational and collaborative competencies.

The lower scores in 'Principle of Reaction' and 'Social System' aspects are affected by some factors, such as (1) *Knowledge asymmetry*. Teachers from Impact Schools (IS) entered the program with minimal STEM background, creating an uneven knowledge distribution within the learning community. This asymmetry inhibited meaningful dialogue during collaborative planning sessions. Interview data revealed that IS teachers felt "uncertain about what to contribute" and "hesitant to ask questions that might seem basic." This finding aligns with Akaygun & Aslan-Tutak's (2016) observation that insufficient conceptual grounding limits teachers' ability to engage in productive STEM discourse. (2) *Ambiguous role definitions*. The initial guidebook lacked operational clarity regarding stakeholder responsibilities. NS teachers expected IS participants to actively co-plan lessons, while IS teachers understood their role as primarily observational. This role confusion resulted in passive participation and missed collaborative opportunities. As one IS teacher stated in post-cycle interviews: "We thought we were here to learn by watching, not to contribute to the design." (3) *Insufficient engagement time*. The single workshop session provided a limited opportunity for IS teachers to internalize STEM principles

before being expected to collaborate on lesson design. Research by Desimone and Garet (2015) indicates that effective professional development requires 30-100 hours of engagement; Cycle 1 provided approximately 12 hours, which proved inadequate for developing collaborative confidence. (4) *Cultural Barriers to Collaboration*. Indonesian educational culture often emphasizes hierarchical relationships and deference to expertise. IS teachers' reluctance to question or contribute may reflect cultural norms where junior or less-experienced teachers defer to those perceived as more knowledgeable. This cultural dimension requires explicit attention in collaborative models.

To address this challenge, increasing the time allocated for discussion during STEM workshops is recommended, as it provides teachers with greater opportunities to internalize STEM principles. Furthermore, the use of accessible instructional resources, such as STEM-based teaching examples available on platforms like YouTube, can help bridge gaps in understanding by offering concrete illustrations of how theory is applied in practice.

Equally important is the role of collaboration in the habituation process. Effective implementation of STEM-LC requires not only cooperation among participants within the same school or learning community but also engagement with experts from higher education institutions. Such partnerships can enhance the quality of instructional design and provide ongoing support, ultimately leading to more effective and sustainable STEM practices in schools.

According to the findings of So et. al. (2020); Akaygun & Aslan-tutak (2016); and Margot & Kettler (2019), a collaborative

approach in preparing teachers for STEM implementation is crucial. Besides, partnerships between University faculty and school teachers can also create effective communities of practice for developing material in science education.

In the original design of the STEM-LC model, the development of lesson plans was intended to be a collaborative effort involving teachers from the NS and those from the Impact School (both IS A and IS B). However, during implementation, this collaboration did not proceed as expected. Teachers from the Impact Schools did not participate in the lesson planning stage. Likewise, during the instructional sessions, they acted merely as observers and did not actively engage in the teaching process. Even during the reflection sessions, their input was minimal.

To address this issue, collaboration among members of the STEM-LC was strengthened by clarifying the roles and responsibilities of each party in the STEM-LC guidebook. For example, the role of the NS as the coordinator of STEM-LC activities

was specified in greater detail. Similarly, the responsibilities of IS during the lesson planning stage were clearly outlined. Additionally, guidelines were established regarding the level of participation allowed for observers from the IS during instructional implementation whether they were to remain as observers or could be actively involved.

This revised approach was implemented in the second cycle. During the lesson planning phase, joint discussions were held alongside hands-on practice to test and refine the STEM project designs collaboratively with all members of the learning community. A focus group discussion (FGD) was also conducted with experts from the university to provide theoretical reinforcement and professional support.

These efforts resulted in a significant improvement in the quality of STEM-LC implementation across all learning communities in Cycle 2, as shown in Figure 5 below.

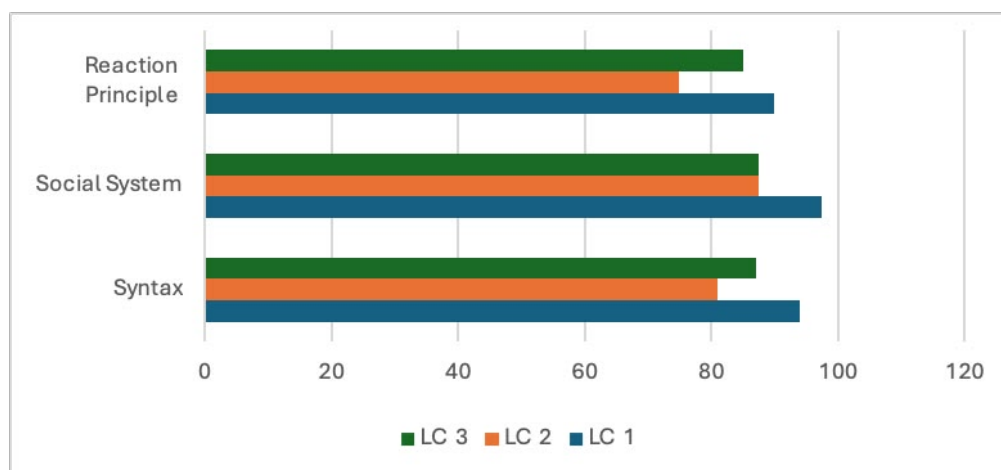


Figure 5. The practicality of STEM-LC Implementation on the Second Cycle

The implementation of STEM-LC in the second cycle proceeded more effectively, as indicated by an average implementation score of 91. It seems that the stages of

activities (syntax) and the interactions among participants (principle of reaction) were carried out effectively, following the design outlined in the STEM-LC model guidebook.

Likewise, the roles of each participant (social system) were performed much more effectively compared to the first cycle.

Related to the aspect of the "reaction principle", although the overall implementation of STEM-LC progressed well across all learning communities (LCs), participant interaction in LC 2 was not as strong as in the other LCs, with a collaboration score of 75. Not all participants in LC 2 were actively involved in providing feedback or suggestions during the lesson planning and instructional phases, despite having received comprehensive materials on STEM during the workshop. In contrast, collaboration in LC 1 and LC 3 was highly effective. For instance, during the lesson plan development stage in LC 1, both the lesson plan and the STEM project topic were discussed collaboratively. Participants also simulated possible classroom scenarios to anticipate unexpected student creativity during the implementation phase.

The variation in 'principle of reaction' scores across LC 1 (100), LC 2 (75), and LC 3 (100) illuminates the importance of social capital in collaborative learning: (1) Learning Community (LC) 1 and Learning Community (LC) 3: Prior collaborative relationships among schools created established trust, communication norms, and shared professional language. These communities exhibited "collaborative fluency" the ability to quickly coordinate, disagree productively, and build on each other's ideas. (2) Learning Community (LC) 2: Geographic distance and lack of prior relationships required participants to learn STEM content while simultaneously

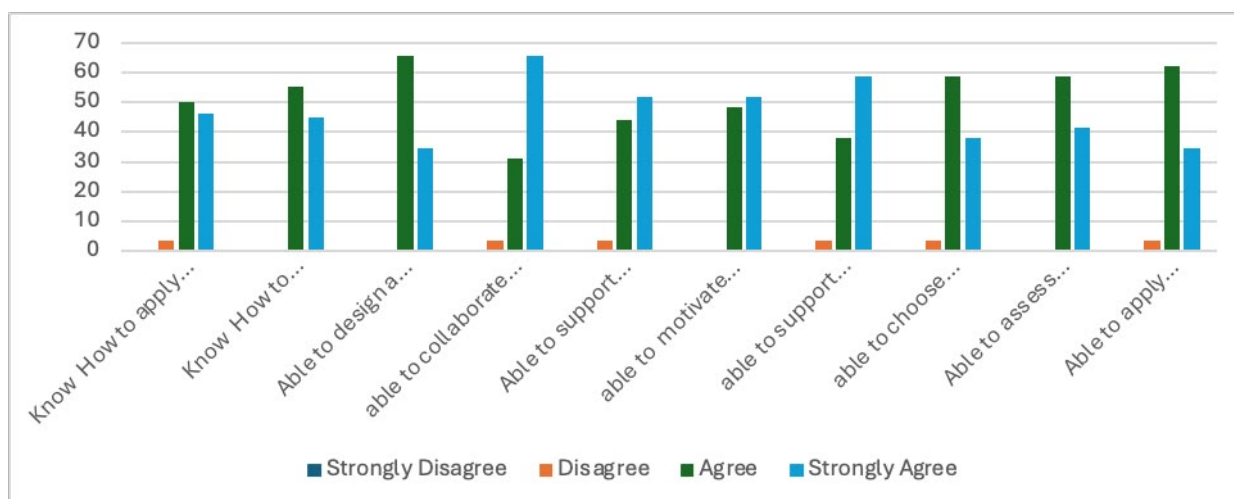
establishing collaborative norms. As one LC 2 teacher noted: "We were still getting to know each other while trying to design complex lessons." This dual cognitive load reduced collaborative effectiveness.

This suggests that a more extended engagement period may be necessary to foster stronger relationships and enhance collaboration among participants in learning communities with limited prior interaction.

This shows that the STEM-LC model is running well and has the potential to achieve the STEM-LC goals as expected. Through good collaboration, the objectives of STEM Education can be achieved, as found by [Samsudin et al. \(2025\)](#), that teacher collaboration positively impacts STEM education and student achievement in schools. Collaboration between teachers and STEM professionals can enhance teachers' understanding of STEM concepts and improve their ability to implement integrated STEM activities. Collaborative relationships between math and science teachers can lead to more effective implementation of integrated STEM units ([Lehman et al., 2014](#)).

### 1) Teacher's Understanding of STEM

Teachers' understanding of STEM is one of the critical indicators of the implementation of the STEM-LC activity stages. The following is the percentage of teachers' understanding regarding the application of STEM education in schools in the second cycle.



**Figure. 6. Teachers' understanding of the implementation of STEM education**

The data presented in Figure 6 illustrates teachers' understanding at the end of the second cycle of STEM-LC regarding various components of STEM implementation. These include how to apply STEM principles in instruction, select appropriate learning materials, design STEM-based projects, collaborate with other STEM teachers, encourage students to solve real-world problems, motivate students to engage with STEM content, promote active student participation, select suitable media, and conduct assessments aligned with STEM-based learning.

Overall, approximately 96.6% of teachers demonstrated a sound understanding of STEM and the ability to implement STEM-based teaching practices effectively. This result supports the prior efforts made during the STEM-LC program to deepen teachers' conceptual understanding before the implementation of STEM lessons in the classroom.

The 96.6% teacher success rate in STEM implementation achieved through STEM-LC compares favorably with international outcomes. In Margot and Kettler's (2019) systematic review of STEM teacher education programs across multiple countries, typical implementation rates

ranged from 60-75% following traditional professional development. Similarly, a study of STEM integration in Australian schools (Tytler et al., 2019) reported that only 68% of trained teachers sustained STEM practices beyond the initial training year.

Several factors may explain STEM-LC's superior outcomes, such as: (1) *Sustained Support Structure*. Unlike time-limited interventions common in other contexts, STEM-LC provides ongoing peer support and accountability. Akaygun and Aslan-Tutak's (2016) Turkish study similarly found that sustained collaborative structures yielded higher implementation rates than isolated workshops. (2) *Context-Embedded Learning*. By conducting professional learning within teachers' actual schools using locally relevant problems, STEM-LC addresses the "transfer gap" identified by Kennedy and Odell (2014) in US professional development programs, where teachers struggle to apply workshop learning to their specific classroom contexts. (3) *Distributed Expertise Model*: The Nucleii School/Impact School structure distributes STEM expertise across multiple sites, creating redundancy and sustainability. This contrasts with "expert dependency" models standard in Western contexts, where STEM

implementation often collapses when external facilitators withdraw (Borko et al., 2014).

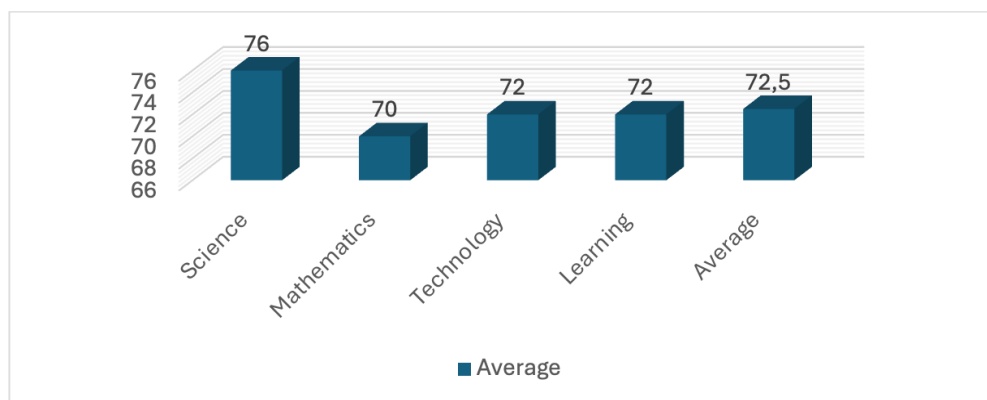
These findings are consistent with those of Syafril (2021), who emphasized that effective STEM implementation requires high-quality teachers those who possess a firm grasp of STEM concepts and the ability to design integrated learning experiences. Similarly, Hrynevych et al. (2022) argue that improving science and mathematics literacy through STEM education depends on several key factors, including teacher proficiency, access to adequate resources, student motivation, and the integration of practice-oriented content.

A strong understanding of STEM and the teacher's ability to motivate students to solve problems using STEM learning, as demonstrated in this research, form the foundation for the sustainability of the STEM-LC habituation model on a larger scale, with support from various stakeholders. The success of the habituation, according to Hartati and Hidayat (2021), is influenced by careful planning, execution, and evaluation, with support from communities and the government. However, there are several interesting points raised by the participating teachers, including students' interest in continuing to learn through STEM and concerns about the sustainability of the STEM program if not supported by funding and resources. This aligns with the research by Purbonuswanto et al. (2024), which highlights that key factors for STEM implementation include teacher competence and student motivation, alongside critical aspects such as infrastructure, resources, and professional development, while challenges

include inadequate laboratory facilities and a lack of financial resources. This certainly presents challenges that need to be addressed. Continued research and development of effective teacher education programs are necessary to realize the benefits of STEM fully.

## 2) Students' Perception Response toward STEM-based Project Learning

Student responses to STEM-based project learning, as part of the STEM habituation activities within the STEM-LC framework, are critically important for identifying whether the learning process has been effectively implemented and whether it successfully engages students. STEM-based learning takes place in 2 phases. In the first phase, the teacher presents a problem that must be solved, and students learn to understand the problem. Furthermore, in groups, students design solutions to the problem by designing simple tools and presenting them in front of the class. In the second phase of learning, each group makes the tools that have been designed in the first phase, and then tests and discusses the tools. In the discussion session, students' problems related to making and how the tools work were discussed. In addition, the relationship between each aspect of STEM in creating and how the tools work was also discussed. To get input on the progress of learning, learning phases 1 and 2 in all learning communities were observed. In addition to the model teacher, all LC members act as observers. The observation results were then followed up on to improve phase 2 learning. The following are student responses to STEM-based learning in the second cycle.



**Figure 7. Students' Attitude toward STEM**

Figure 7 indicates that students responded positively to the learning process. This positive response is reflected in the engaging and challenging nature of the lessons, which encouraged them to solve problems through project-based activities. The issues discussed were closely related to students' everyday experiences at school, such as how to address the shortage of clean water, water wastage due to students forgetting to turn off the taps after use, puddles in the schoolyard caused by tidal flooding or heavy rain, and water pollution in the school's fishpond or garden pond (Prastikawati et al., 2025). Additionally, the unconventional interaction during lessons also boosts students' enthusiasm. After the first cycle of STEM implementation, some students even asked the teacher when they would learn using this method again.

Figure 7 also shows that each aspect of STEM and all stages of STEM-based learning were implemented effectively. Among the four components Science, Technology, Engineering, and Mathematics Science was perceived as the most prominent and best understood by students. In the students' STEM projects, the interconnection between science, technology, and engineering was well integrated. Still, on the contrary, mathematics is less related and less

understood in its relationship to other aspects.

An illustrative example emerged from Phase 1 of the learning activities in LC 3, where the issue of flooding was examined in terms of its causes and possible solutions. One solution implemented by students was the construction of biopores to facilitate water infiltration. This project-based activity provided an opportunity for students to explore the scientific and engineering aspects of the problem. Ideally, students were expected to understand how the shape and diameter of biopores influence the rate and efficiency of water absorption a clear link to both scientific reasoning and mathematical modeling.

However, observations revealed a missed opportunity to integrate mathematics meaningfully into the learning process. Although the activity itself had the potential to engage students in calculating volume, surface area, or analysing rates of water absorption, the teacher did not explicitly relate these practical aspects to mathematical concepts. As a result, the STEM integration was incomplete, with the "Mathematics" component remaining underdeveloped.

The findings highlight the need for more structured guidance and support for teachers in making interdisciplinary connections, particularly in integrating mathematics into

real-world problem-solving contexts. Effective STEM implementation not only requires well-designed projects but also depends heavily on the teacher's ability to connect disciplinary knowledge in meaningful and explicit ways. Research by

Srikoon et al. (2024) has demonstrated that the integration of mathematics into STEM-based learning can significantly enhance students' mathematical literacy and problem-solving abilities.



Figure 8. Integrating math in "Biopores hole project"

This finding was subsequently addressed in Phase 2, where the teacher made an effort to relate mathematical concepts to the STEM activity explicitly. In this phase, the teacher introduced the idea of the area of the bio-pores opening in connection with the volume of organic waste that could be accommodated within the cylindrical hole. By doing so, students were

encouraged to apply mathematical reasoning such as calculating the surface area and volume of a cylinder in a practical, real-world context. This integration marked a significant improvement in the alignment of the activity with the principles of STEM education, particularly in reinforcing the often-overlooked mathematics component.

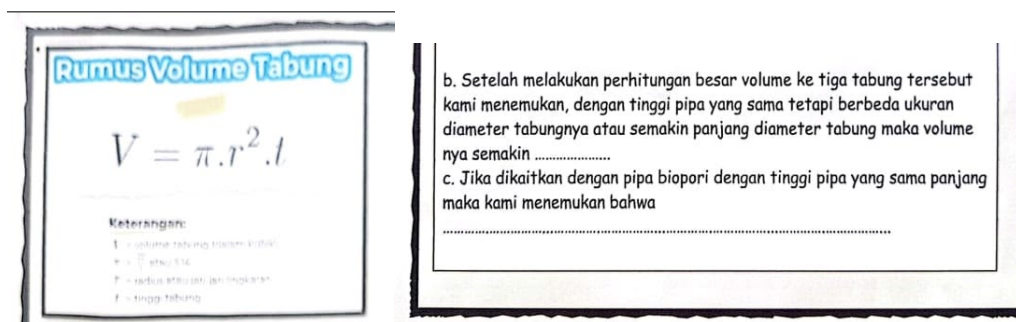


Figure 9. Integration of math concepts to STEM projects in student worksheets

In the student worksheet, students were given questions:

*Calculate the volume of 3 (three) cylinders using the cylinder volume formula. If the diameter is 14 cm and the height of cylinder A = 10 cm,*

cylinder  $B = 20$  cm, and cylinder  $C = 30$  cm, compare the volume of the three cylinders.

Complete the blank statements below:

*After calculating the volume of the three cylinders, we found that with the same pipe height but different diameter sizes, the larger the diameter of the cylinder, the volume of the cylinder will be.....*

*If associated with bio-pore holes with the same height (and different diameters), then we found that.....*

In another project, students explore ways to reduce water waste in their schools by creating a simple automatic water tap. The relationship between the science concept of pressure and the concepts of technology and engineering is relatively straightforward, although the mathematical concept is not overly dominant. According to Syafril (2021), the interconnection between all aspects of STEM does not always have to be dominant. In some designs, one aspect of STEM may not be very prominent, but efforts are still made to relate it to other STEM aspects.

In addition to integrating the concepts of Science-Technology-Engineering-Mathematics, STEM-based projects in phase 2 are also engaging and spark a lot of creativity. Some mistakes led to new ideas. In the learning project of making an automatic water tap from used bottles in LC 1, students found that during testing, the water tap they designed could not close automatically as expected. The teacher then asked;

*"What causes the tap to have difficulty shutting off? What if we change the volume of water in the plastic bottle? Does that affect the tap?"*

Questions like these encouraged students to experiment with various ideas, ultimately

leading to a solution that allowed the tap to shut off automatically. During their project presentation, one group even concluded:

*"There are four factors that contributed to our group's failure in creating this automatic tap: the volume of water in the bottle, the improper placement of the rubber seal, the balance of the bottle, and the messy adhesive application."*

However, during the STEM learning process, the difficulties and problems faced by the students allowed them to learn from their mistakes and generate new ideas. For example, in the group where the water filtering device failed to produce clean water, one student suggested,

*"Should we just take it apart?"*

*"What if we start over?"*

*"Maybe we need to change the arrangement of the filter materials; the water got cloudier because the sand dissolved."*

The students then used their gadgets to try searching the internet and looking for information on how to repair the tools they made.

This situation suggests that the STEM learning approach effectively encourages students to think critically and analyze the mistakes they made to produce better outcomes. Multiple studies have demonstrated significant improvements in critical thinking abilities and academic achievement when implementing STEM-based instruction compared to traditional methods. The STEM approach encourages students to analyze problems, explore solutions, build knowledge independently, and even close the academic gap among students (Mohd Saat et al., 2019; Teo et al., 2021; Wandika, 2023).

Findings from classroom observations of STEM-based learning indicate that the establishment of learning communities within the STEM-LC framework

significantly supported teachers in understanding STEM concepts and in implementing STEM-based projects to improve instructional quality. The student-designed STEM projects, which integrated concepts from science, technology, engineering, and mathematics, fostered collaboration and discussion, thereby stimulating students' critical thinking. Within STEM-based projects, activities such as discussion, collaboration, and even mistakes made during the design and testing phases served as essential factors in promoting students' creativity and critical thinking skills. These elements reflect the authentic, problem-solving nature of STEM education and highlight the pedagogical value of allowing students to engage deeply with real-world challenges.

While the STEM-LC model demonstrated effectiveness in this implementation, several significant limitations constrain its generalizability and scalability. (1) *Resources, Dependencies, and Time Allocation*. The model's success relied on factors that may not be universally available, such as material resources and time allocation. Despite emphasizing low-cost projects, STEM activities still required materials (PVC pipes, filters, bottles) that resourced schools could provide, but impoverished schools might struggle to sustain (Harste et al., 2004). Student feedback indicated concerns about "continuing STEM if we have to buy materials ourselves". In the case of time allocation, teachers invested approximately 40-50 hours across five months. This substantial time commitment may be unsustainable without administrative support or compensation, particularly in schools with high teaching loads. (2) *Selection Bias and Generalizability*. The ten schools were purposively selected rather than randomly

assigned, likely representing higher-capacity, more motivated institutions. Effectiveness in resistant or lower-capacity schools remains untested. Besides, all schools were located in Banjarmasin, an urban center with relatively better infrastructure than rural Indonesian schools. Rural implementation may face additional challenges related to connectivity, resource access, and teacher qualifications (Korthagen et al, 2010). (3) *Sustainability Concerns*. School administrator support proved crucial for time allocation and resource provision. Leadership changes could disrupt established learning communities, as documented in Vangriecken et al.'s (2015) study of teacher community stability.

#### 4. Conclusion

Based on the research findings, it can be concluded that the STEM-LC model is an effective approach for habituating STEM integration practices among Indonesian science teachers. The model's core components syntax, social system, and principle of reaction proved to be well structured and practically implementable, achieving an overall effectiveness score of 9, with the social system component receiving the highest rating. The structured five-phase implementation process successfully facilitated the progressive habituation of STEM practices, even among teachers initially unfamiliar with STEM pedagogy.

The STEM-LC model yielded significant positive outcomes; 96.6% of participating teachers successfully integrated the STEM approach into their science instruction, demonstrating measurable improvement in both pedagogical understanding and instructional design capabilities. Students responded favorably (score 72.5), expressing sustained engagement and continued interest in STEM

learning activities. The collaborative, community-based structure of the model proved instrumental in building teacher confidence and competence, transforming STEM from an abstract concept into practical, habituated classroom practice.

These findings confirm that the STEM-LC model is not only viable but also scalable as a sustained professional development strategy for advancing STEM education across Indonesian schools. The community-based approach addresses key barriers to STEM adoption by providing ongoing peer support, shared learning experiences, and reflective practice opportunities that enable lasting pedagogical change.

The recommendations for further study are that the educational authorities are encouraged to integrate the STEM-LC model into teacher professional development programs formally. Clear policy support at the local and national levels would provide the necessary framework to sustain and expand STEM practices in schools. To foster stronger collaboration and familiarity among participants, particularly in geographically dispersed learning communities, it is recommended that the duration of STEM-LC activities be extended. Longer engagement can improve team cohesion and enhance collaborative outcomes. Teachers require ongoing support to deepen their understanding of interdisciplinary STEM integration, particularly in linking scientific and mathematical concepts with real-world applications. Workshops, mentoring, and university partnerships should be maintained or expanded. As observed in the study, mathematics tends to be underrepresented in some STEM project implementations. Future iterations of STEM-LC should include specific strategies and examples to ensure mathematics is meaningfully integrated, and continuous assessment and reflective

practices should be embedded in the implementation to monitor progress and identify areas for improvement. Feedback loops among teachers, students, and facilitators can help adapt the model to various school contexts.

## 5. References

- Afriana, J., Permanasari, A., & Fitriani, A. (2016). Penerapan project based learning terintegrasi STEM untuk meningkatkan literasi sains siswa ditinjau dari gender. *Jurnal Inovasi Pendidikan IPA*, 2(2), 202.  
<https://doi.org/10.21831/jipi.v2i2.8561>
- Akaygun, S., & Aslan-Tutak, F. (2016). STEM Images Revealing STEM Conceptions of Pre-Service Chemistry and Mathematics Teachers. *International Journal of Education in Mathematics, Science and Technology*, 4(1), 56.
- Annisa, N., Asrizal, & Festiyed. (2022). Effects of STEM-based learning materials on knowledge and literacy of students in science and physics learning: A meta-analysis. *Journal of Physics: Conference Series*, 2309(1), 012063. <https://doi.org/10.1088/17426596/2309/1/012063>
- Astawan, I. G., Suarjana, I. M., Werang, B. R., Asaloei, S. I., Sianturi, M., & Elele, E. C. (2023). STEM-Based Scientific Learning and Its Impact on Students' Critical and Creative Thinking Skills: An Empirical Study. *Jurnal Pendidikan IPA Indonesia*, 12(3), 482–492. <https://doi.org/10.15294/jpii.v12i3.46882>
- Borko, H., Jacobs, J., & Koellner, K. (2014). Contemporary approaches to teacher professional development. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International encyclopedia of education* (3rd ed., pp. 548-556). Elsevier.
- Desimone, L. M., & Garet, M. S. (2015). *Best practices in teachers' professional development in the United States*.

- Psychology, Society and Education, 7(3), 252-263.
- Dewey, J. (1938). Experience and education. Macmillan.
- Chowdhury, S. A., Arefin, A. S., & Ahmed, F. (2020). Factors Behind The Implementation of STEM Education In Bangladesh. *Journal Of Physics*, 36(1), 24-34. <https://doi.org/10.1088/1742-6596/1563/1/012064>
- Harste, J., Leland, C., Schmidt, K., Vasquez, V., & Ociepka, A. (2004). Practice Makes Practice, or Does It? The Relationship Between Theory and Practice in Teacher Education. *ResearchGate*.
- Hartati, D., & Hidayat, S. (2021). Pendidikan Karakter Berbahasa Santun Dengan Model Habitiasi di SD Laboratorium Upi Kampus Tasikmalaya. *Pedadidaktika: Jurnal Ilmiah Pendidikan Guru Sekolah Dasar*, 8(3), 584-593.
- Hrynevych, L. M., Khoruzha, L. L., Rudenko, N. M., & Proshkin, V. V. (2022). STEM education in the context of improving the science and mathematics literacy of pupils. *J. Phys.: Conf. Ser.*, 2288 012031.
- J Akker, Bannan, B., Kelly, A., Nieveen, N., & Plomp, T. (2010). *An introduction to educational design research*.
- Jackson, C., Mohr-Schroeder, M., Bush, S., Maiorca, C., Roberts, T., Yost, C., & Fowler, A. (2021). Equity-Oriented Conceptual Framework for K-12 STEM literacy. *International Journal of STEM Education*, 8(38). <https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-021-00294-z>
- Joyce, B., Weil, M., & Calhoun, E. (2014). *Models of Teaching* (9th ed.). Pearson Education.
- Kennedy, M. M., & Odell, S. J. (2014). Collaborative professional learning. In L. E. Martin, S. Kragler, D. J. Quatroche, & K. L. Bauserman (Eds.), *Handbook of professional development in education* (pp. 449-468). Guilford Press.
- Khoiri, A. (2019). Meta Analysis Study: Effect of STEM (Science Technology Engineering and Mathematic) towards Achievement. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, 9(1). <https://doi.org/10.30998/formatif.v9i1.2937>
- Korthagen, F. A. J. (2010). The Relationship Between Theory and Practice in Teacher Education. In E. Baker & B. McGaw (Eds.), *Penelope Peterson* (pp. 669-675). Elsevier.
- Lehman, J., Kim, W., & Harris, C. A. (2014). Collaborations in a Community of Practice Working to Integrate Engineering Design in Elementary Science Education. *Journal of STEM Education: Innovations and Research*, 15, 21-28.
- Lutfi, L., Azis, A. A., & Ismail, I. (2018, October). Pengaruh Project Based Learning Terintegrasi Stem Terhadap Literasi Sains, Kreativitas dan Hasil Belajar Peserta Didik. *Seminar Nasional Biologi*.
- Magdalena, A., M. ., Putra, A. P. ., Winarti. (2021). The Practicality of E-LKPD Materials on Environmental Pollution to Practice Critical Thinking. *BIO-INOVED*, 3(3). <http://dx.doi.org/10.20527/bino.v3i3.11099>
- Mahoney, M. P. (2010). Students' Attitudes Toward STEM: Development of an Instrument for High School STEM-Based Programs. *Journal of Technology Studies*, 36(1).
- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *IJ STEM Ed*, 6, 2. <https://doi.org/10.1186/s40594-018-0151-2>
- Mohd Saat, R., Yaki, A. A., V. Sathasivam, R., & Zulnaldi, H. (2019). Enhancing Science Achievement Utilising an Integrated STEM Approach. *Malaysian Journal of Learning and Instruction*,

- 16(1), 181–205. <https://doi.org/10.32890/mjli2019.16.1.8>
- Mwembe, D. Z., L., I., & Mdlongwa, P. (2022). Needs Assessment for Facilitators in Teaching of STEM Subjects in Under Resourced Rural Schools; Case of Lupane and Hwange Districts in Zimbabwe. *International Journal of Professional Development, Learners and Learning*, 4(1), 2202. <https://doi.org/10.30935/ijpdll/11666>
- Nguyen, N. T. H., Nguyen, M. N., & Hung, N. V. (2024). Current Situation And Solutions To Improve The Quality Of Teaching In STEM Education In General Schools: A Case Study In Some Northern Provinces Of Vietnam. *European Journal of Education*, 16, 2024. <https://doi.org/10.46827/ejes.v11i1.5172>
- Nilvo, J. (2023). The Importance of Increasing STEM Literacy Now to Help Solve Global. *DoDSTEM*. [Internet. <https://www.dodstem.us/meet/blog/entries/increasing-stem-literacy/>
- Plomp, T. (2020). Educational Design Research: An Introduction. In T. P. & N. Nieveen (Ed.), *An Introduction to Educational Design Research* (pp. 9–35). slo netherlands.
- Prastikawati, E. F., Adeoye, M. A., Curle, S., & Riwayatiningih, R. (2025). Beyond the Classroom: Investigating Learning and Motivation among EFL Undergraduate Students in Indonesia. *Indonesian Journal on Learning and Advanced Education*, 7(2).
- Purbonuswanto, W., Sutama, S., Supriadi, D., Adnan, M. B., & Waluyo, M. (2024). Transforming Educational Leadership: Digital Applications of Ki Hajar Dewantara's Leadership Principles. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 422-437.
- Russo, A. (2020). Recession and automation changes our future of work, but there are jobs coming, report says. *World Econ Forum [Online]*.
- Samsudin, M., Sari, R., & Hanafi, A. I. (2025). Strategic Pathways to Educational Excellence: An ISM Analysis of Leadership, Curriculum, and Service Quality in Muhammadiyah Schools Amid Society 5.0. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 361-374.
- Sarioğlu, A. B., & Özkaya, Ö. Ş. (2023). Web Integrated STEM Learning: Effects on Students' Academic Achievement, Creativity and Metacognitive Awareness. *Journal of Science Learning*, 6(3), Article 3. <https://doi.org/10.17509/jsl.v6i3.56477>
- So, W., W, M., He, Q., Chen, Y., & Chow, C. F. (2020). School-STEM Professionals' Collaboration: A case study on teachers' conceptions. *Asia-Pacific Journal of Teacher Education*, 49(3), 300–318. <https://doi.org/10.1080/1359866X.2020.1774743>
- Srikoon, S., Khamput, C., & Punsrigate, K. (2024). Effects of the stemen teaching models on mathematical literacy and mathematical problem-solving. *Malaysian Journal of Learning and Instruction*, 21(2), 79–115. <https://doi.org/10.32890/mjli2024.21.2.4>
- Suhirman, S., & Prayogi, S. (2023). Overcoming Challenges in STEM Education: A Literature Review That Leads to Effective Pedagogy in STEM Learning. *Jurnal Penelitian Pendidikan IPA*, 9(8), 432–443. <https://doi.org/10.29303/jppipa.v9i8.4715>
- Syafril, S. (2021). Mini review: Improving teachers' quality in STEM-based science teaching-learning in secondary school. *J. Phys.: Conf. Ser*, 012072. <https://doi.org/10.1088/1742-6596/1796/1/012072>
- Syahmani, S., Rahmatilah, J., Winarti, A., Kusasi, M., Iriani, R., & Prasetyo, Y. D. (2022). Development of Guided Inquiry Lesson Based on Ethnoscience E-Modules to Improve Students' Problem-solving Ability in Chemistry Class.

- Journal of Innovation in Educational and Cultural Research*, 3(4), 670–682. <https://doi.org/10.46843/jiecr.v3i4.363>
- Teo, T. W., Tan, A. L., Ong, Y. S., & Choy, B. H. (2021). Centricities of STEM curriculum frameworks: Variations of the S-T-E-M Quartet. *STEM Education*, 1(3), 141–156. <https://doi.org/10.3934/steme.2021011>
- Tuong, H. A., Nam, P. S., Hau, N. H., Tien, V. T. B., Lavicza, Z., & Houghton, T. (2023). Utilizing STEM-based practices to enhance mathematics teaching in Vietnam: Developing students' real-world problem solving and 21st century skills. *JOTSE: Journal of Technology and Science Education*, 13(1), 73–91. <https://doi.org/10.3926/jotse.1790>
- Tytler, R., Mulligan, J., Prain, V., White, P., Xu, L. H., Kirk, M., Nielsen, C., & Speldewinde, C. (2019). An interdisciplinary approach to primary school mathematics and science learning. *International Journal of Science Education*, 41(8), 1089–1108.
- Vangrieken, K., Dochy, F., Raes, E., & Kyndt, E. (2015). Teacher collaboration: A systematic review. *Educational Research Review*, 15, 17–40.
- Wandika, U., W. ., Asrizal. (2023). The Effect Of Stem-Based Learning Approaches On Critical Thinking Abilities And Student Learning Outcomes: Meta-Analysis. *Jurnal Penelitian Pembelajaran Fisika*, 9(2), 194–201. <https://doi.org/10.24036/Jppf.V9i2.122602>
- Wang, L.-H., Chen, B., Hwang, G.-J., Guan, J.-Q., & Wang, Y.-Q. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education*, 9(1), 26. <https://doi.org/10.1186/s40594-022-00344-0>
- Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.
- Winarti, A., Iriani, R., Butakor, P. K., Meiliawati, R., & Syarpin, S. (2023). Transcript-Based Lesson Analysis: The Analysis of Classroom Communication in Chemistry Implementing Case-Based and Project-Based Learning. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 6(1), 1–13. <https://doi.org/10.23917/ijolae.v6i1.23160>
- Winarti, A., Rahmini, A., & Almubarak, A. (2019). The effectiveness of multiple intelligences based collaborative problem solving to improve critical thinking. *Jurnal Kependidikan Penelitian Inovasi Pembelajaran*, 3(2), 172–186.
- Winarti, A., Yuanita, L., & Nur, Moh. (2019). The effectiveness of multiple intelligences based teaching strategy in enhancing the multiple intelligences and science process skills of junior High School students. *Journal of Technology and Science Education*, 9(2), 122. <https://doi.org/10.3926/jotse.404>
- Zakiah, R. N., Ibrohim, & Suwono, H. (2021). *The influence of science, technology, engineering, mathematic (STEM) based biology learning through inquiry learning models towards students' critical thinking skills and mastery of biological concepts*. 030061. <https://doi.org/10.1063/5.0043361>