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Comparative study of fundamental mathematical competences in STEM learning: Objective, implications, and obstacles in Indonesia and Malaysia

Sri Hastuti Noer[1*], Mella Triana[1], Mohamad Ikram Zakaria[2], Nurain Suryadinata[1], Widyastuti[1]

[1]Department of Mathematics Education, Universitas Lampung, Lampung, Indonesia
[2]Department of Innovative Science and Mathematics Education, Universiti Teknologi Malaysia, Johor, Malaysia
[*]Correspondence: sri.hastuti@fkip.unila.ac.id

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Abstract

Indonesia and Malaysia both prioritize STEM education, offering a relevant context for comparing practices that support students' fundamental mathematics competencies (FMC). This comparative study aims to examine and analyze the implementation of STEM in mathematics instruction in both countries, while also identifying the challenges faced by teachers. Furthermore, it explores how STEM practices relate to students' FMC and 21st-century skills, and assesses the extent to which the resulting models can be applied in other contexts. Four junior high schools (two per country) that had implemented STEM in mathematics were selected purposively, involving four mathematics teachers and 115 students (64 Indonesian, 51 Malaysian). Data were collected through video-recorded lesson observations, semi-structured teacher interviews, a Student Perceptions of Learning questionnaire, and an FMC test. Findings revealed that STEM practices in both countries were closely aligned, combining hands-on and minds-on activities, while teachers creatively compensated for limited infrastructure. Students in both countries reported positive perceptions of critical thinking, problem-solving, collaboration, and communication. Malaysian students showed greater gains in creativity, technology use, and collaboration, whereas Indonesian students were stronger in communication. Comparable FMC test performance suggests high potential for adopting, adapting, and validating the pedagogical model across countries. STEM integration facilitated active learning and deeper conceptual understanding of mathematics.

Keywords:
Fundamental mathematical competences, Indonesia, Malaysia, STEM

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1. INTRODUCTION

Education plays a crucial role in creating high-quality human resources. One field of education that plays a crucial role in enhancing the quality of education is mathematics. Mathematics supports the development of logical reasoning, critical thinking, creative thinking, spatial thinking, develops problem-solving skills, and plays a vital role in everyday life as well as across various scientific disciplines (Sharma, 2021). The importance of mathematics in everyday life necessitates that people study mathematics and master fundamental mathematical competencies. Mathematical competence is knowledge, skill, and ability to use mathematics for solving problems of both mathematical and non-mathematical context (Masduki et al., 2019). Mathematical competencies can be conceptualized as layers of knowledge, with numeracy skills as the foundational core and more complex mathematical skills as the additional layers over the core, related hierarchically, capturing the increasing complexity of symbolic mathematical skills (Xu et al., 2023).

Niss and Højgaard (2011) introduced eight mathematical competencies in the KOM Project (Competencies and Mathematical Learning) report, which consist of mathematical thinking competency, problem tackling competency, modelling competency, reasoning competency, representing competency, symbols and formalism competency, communicating competency, aids and tools competency. This framework serves as the foundation for the development of mathematical competency frameworks widely used in educational research, including the basis for the development of the PISA framework of Fundamental Mathematical Competencies (FMC). OECD (2019) framework defines seven fundamental mathematical competencies, including communication, mathematizing, representation, reasoning and argumentation, devising strategies for solving problems, using symbolic, formal, and technical language and operations, and using mathematical tools. Together, these competencies enable learners to interpret real-world situations mathematically, construct and evaluate mathematical models, select appropriate representations and solution strategies, manipulate mathematical language and symbols, use technological and physical tools effectively, and communicate mathematical ideas and solutions.

According to the above frameworks, fundamental mathematical competences provide the foundation for students to apply mathematics meaningfully in solving authentic and interdisciplinary problems. Therefore, learning approaches that promote interdisciplinary integration and authentic problem solving are essential for fostering these competencies. One learning approach that reflects these characteristics is STEM (Science, Technology, Engineering, and Mathematics), which integrates science, technology, engineering, and mathematics to create meaningful learning experiences that connect mathematical concepts with real-world contexts. STEM learning aims to equip students with the knowledge, skills, and competencies needed to address increasingly complex global challenges through learning experiences that involve authentic and interdisciplinary problem solving (McGunagle & Zizka, 2020). In STEM learning, students actively participate in authentic real-world situations that require the integration of science, technology, engineering, and mathematics to address practical problems, thereby fostering a deeper understanding of the relationships among these disciplines (Suherman et al., 2025). The implementation of STEM in learning has provided opportunities for students and teachers to enrich communication, creativity, imagination,

observation, perception, and thinking, thereby developing cognitive skills such as listening, problem-solving, matching form with function, and decision-making (Taylor, 2016). These processes closely correspond to the core dimensions of the FMC framework proposed by OECD (2019), suggesting that STEM provides a theoretically appropriate learning environment for developing students' fundamental mathematical competences.

STEM learning provides authentic contexts for developing communication by engaging students in collaborative discussions, explaining mathematical ideas, and presenting solutions during problem-solving activities (Erviana et al., 2025; Pujawan & Suryawan, 2021). Mathematization is fostered as students translate real-world situations into mathematical models to investigate and solve contextual problems (English, 2023; Roberts et al., 2022). STEM also strengthens representation by encouraging students to express mathematical ideas through graphs, tables, diagrams, and symbolic representations, thereby facilitating conceptual understanding (Erviana et al., 2025; Rasyid, 2024). Through inquiry and problem-based learning, STEM promotes reasoning and argumentation, enabling students to formulate conjectures, justify mathematical solutions, evaluate evidence, and draw logical conclusions (Senawati et al., 2025; Srikoon et al., 2024). Devising strategies for solving problems is developed as students design, test, and refine multiple solution strategies while addressing authentic interdisciplinary challenges (Fajrina et al., 2020; Hidayat & Kastberg, 2025). STEM learning also supports the use of symbolic, formal, and technical language and operations by requiring students to communicate mathematical ideas through formal notation, symbolic expressions, and technical terminology (He, 2022; Raje et al., 2025). Finally, using mathematical tools is enhanced through the integration of technological and digital resources, such as visualization software, graphing applications, and data collection tools, which support mathematical investigation and problem solving (Fajrina et al., 2020; Forde et al., 2023). These findings indicate that STEM learning provides meaningful opportunities to develop the dimensions of Fundamental Mathematical Competences (FMC).

The impact of STEM implementation in several countries has led to the development of STEM research directions. MeriSTEM (2021) reports that "STEM education in Asia is indeed in a strong position to tap into the many opportunities that digital technologies will provide, with a strong focus on the improvement of existing curricula to enhance the components of STEM that address both learner and educator needs to adapt to the impact of 4IR". Reflecting this regional trend, Malaysia has implemented the third phase of its STEM education agenda (2013-2025) by strengthening STEM teaching, enhancing teacher capacity, integrating digital technologies into learning, promoting interdisciplinary approaches, and expanding partnerships with higher education institutions and industry to develop a technologically competent workforce. These initiatives illustrate how regional STEM priorities have been translated into national educational policies, making Malaysia a valuable comparative context for examining STEM implementation in Southeast Asia. The outcomes of these policy initiatives can be indirectly examined through international large-scale assessments, such as the Programme for International Student Assessment (PISA), which provide evidence of students' mathematical achievement as one of the indicators of STEM learning outcomes. The comparison of PISA mathematics scores for Indonesia and Malaysia across the 2012, 2015, 2018, and 2022 assessment cycles is presented in Table 1.

Table 1. Comparison of students' average PISA mathematics scores in Indonesia and Malaysia (2012-2022)

Measurement Period	OECD Average	Indonesia Average	Malaysia Average
2012	488	375	421
2015	485	386	446
2018	487	379	440
2022	472	366	409

As presented in Table 1, both Indonesia and Malaysia consistently performed below the OECD average in mathematics across the 2012-2022 PISA assessment cycles. However, Malaysian students consistently achieved higher average mathematics scores than their Indonesian counterparts. This performance gap highlights the importance of examining STEM implementation in both countries to identify effective educational practices that may contribute to the development of students' FMC. As neighboring Southeast Asian countries that have both prioritized STEM education within their national education systems, Indonesia and Malaysia provide a relevant comparative context for exploring how STEM is implemented and how these practices may inform future improvements in STEM education. Such comparisons are expected to generate valuable insights and practical recommendations for strengthening STEM education and enhancing students' FMC, particularly in Indonesia. In line with this objective, fostering students' curiosity, productivity, and the continuous development of knowledge and competencies has been identified as a key priority for effective STEM education (MeriSTEM, 2021). Recent STEM research in mathematics education has predominantly adopted an outcome-oriented perspective. Studies have mainly examined the effects of STEM on critical thinking, creativity, interdisciplinary thinking, mathematical literacy, character development, and other twenty-first century competencies (Abdurrahman, 2019; Atmojo et al., 2025; Benek & Akçay, 2022; Erviana et al., 2025; Ferdiani & Harianto, 2024; Ferdiansyah et al., 2025; Nugraha et al., 2026; Nurhayati et al., 2016; Prayogi et al., 2024; Sarı et al., 2018; Stehle & Peters-Burton, 2019). Alongside this trend, another body of research has focused on developing STEM-based instructional materials, assessment instruments, digital learning resources, and learning modules (Dewi & Maulida, 2023; Fitri et al., 2020; Gao et al., 2020; Harisman et al., 2025; Pramasdyahsari et al., 2024; Sari et al., 2025). Although several Malaysian studies have begun to investigate teachers' readiness, practice levels, and implementation of STEM learning (Adnan et al., 2025; Ibrahim et al., 2024; Malik et al., 2024; Nasir et al., 2023; Yusoff & Ahmad, 2025), these studies still primarily describe implementation characteristics rather than examining how exemplary teachers translate STEM principles into classroom practice.

Furthermore, STEM research by Indonesian researchers has been conducted in Indonesia, as well as in Malaysia. Collaborative research between the two countries focuses more on teacher readiness and perceptions regarding the integration of Augmented Reality (AR) in STEM education (Sukmawati et al., 2026), exploring teachers' and embedded value-based design in learning activities that are contextually relevant and culturally responsive for inclusive and sustainable STEM learning (Arnab et al., 2025), and setting up specific learning environments for STEM education (Zahir et al., 2024). Consequently, little empirical evidence

explains how exemplary teachers enact STEM during mathematics instruction despite the growing recognition that STEM education is shifting from demonstrating effectiveness toward improving implementation quality. In fact, differences in curriculum, policies, learning cultures, and teacher development practices in the two countries can actually produce richer lessons learned, potentially leading to best practices in STEM implementation.

Recent studies have increasingly focused on developing learning materials, assessment instruments, and digital technologies to support and evaluate the development of FMC in STEM learning. Despite these advances, important gaps remain in the current STEM literature. Existing studies have predominantly examined how STEM learning enhances dimensions of Fundamental Mathematical Competences (FMC), such as communication, reasoning, representation, and problem solving, partially. Consequently, limited attention has been given to understanding how STEM learning supports the integrated development of all seven dimensions of FMC as a comprehensive competency framework proposed by OECD (2019). Moreover, empirical evidence examining how different educational contexts shape the development of FMC through STEM learning remains limited. A more comprehensive analysis of STEM implementation across diverse educational settings is therefore needed to better understand how learning objectives, instructional practices, and implementation challenges collectively contribute to the development of students' Fundamental Mathematical Competences.

This raises the question of how the teaching practices of STEM teachers in Malaysia and Indonesia are: "Are there any best practices that can be taken to improve students' fundamental mathematical competence from this learning?" The relatively similar characteristics of students in Indonesia and Malaysia underscore the urgency to implement this in both countries, allowing them to benefit from the best practices from each.

For this reason, a comparative study was conducted to examine the implementation of STEM in mathematics learning in Malaysia and Indonesia, with the aim of identifying evidence-based best practices that can inform and strengthen STEM implementation in both educational contexts. Specifically, this study compares the objectives of STEM in mathematics learning, its contributions to students' FMC and the implications and challenges associated with its implementation in each country. The study is expected to identify both shared and context-specific best practices that contribute to the development of students' FMC, highlighting strategies that are effective across both countries as well as those shaped by each country's educational context. The findings are expected to provide evidence-based recommendations for strengthening the implementation of STEM in mathematics learning in Indonesia and Malaysia, as well as in educational contexts with similar characteristics.

2. METHOD

2.1. Research Design

This study is a comparative study using a convergent mixed-methods approach to compare students' FMC in STEM learning in Indonesia and Malaysia. This approach was chosen because it allows for the integration of quantitative and qualitative data to yield a more comprehensive understanding of the implementation of STEM learning and the factors

influencing students' FMC. In this study, quantitative and qualitative data were collected during the same period and then analyzed separately using analytical techniques appropriate for the characteristics of each data set. Subsequently, the results of both analyses were integrated during the interpretation phase to obtain a complete picture of the similarities and differences in the implementation of STEM education in both countries, as well as the best practices that support the development of students' FMC.

2.2. Research Subject

The study was conducted at four junior high schools that had implemented STEM education, consisting of two schools in Indonesia and two schools in Malaysia. Schools were selected using purposive sampling, based on the criterion that they had implemented STEM education in mathematics instruction. The participating teachers were mathematics teachers who had implemented STEM education, while students were selected as research respondents based on the classes participating in the program. Overall, the study involved 2 teachers and 115 students, comprising 64 students from Indonesia and 51 students from Malaysia.

2.3. Research Instruments

This study used several instruments to collect quantitative and qualitative data.

2.3.1. Fundamental Mathematical Competency Test

The fundamental mathematics competency test was developed based on the fundamental mathematics competency indicators outlined in OECD (2019) framework, which include communication, mathematizing, representation, reasoning and argumentation, devising strategies for solving problems, using symbolic, formal, and technical language and operations, and using mathematical tools. Prior to its use, the instrument met the criteria for validity and reliability.

2.3.2. Student Perception Survey on STEM Learning

The questionnaire was used to gather information on students' perceptions of the implementation of STEM-based learning during the mathematics learning process. This instrument consisted of two types of questions: closed-ended questions using a four-point Likert scale and open-ended questions that allowed students to provide more in-depth explanations of their learning experiences. Before use, the questionnaire was validated by two experts.

The first section of the questionnaire measures students' perceptions of the implementation of STEM-based learning, including interest in mathematics, the benefits of STEM project-based learning, understanding of the material, project difficulty level, curiosity, project task management, and habits in completing projects. The second section asks students to self-assess their perceived development of several competencies acquired during STEM learning, namely creativity, logical thinking, innovation, problem-solving, collaboration, communication, and the use of technology. The assessment is conducted using a five-point Likert scale, ranging from 1 (not developed at all) to 5 (very well developed). The third section contains questions regarding the availability of learning resources, while the final section

consists of open-ended questions that explore students' experiences with the implementation of STEM learning, such as teacher feedback, group work, opportunities to ask questions, project guidance, rewards, and the aspects of learning that students liked the most.

The data obtained through the questionnaire was not used as the primary basis for comparing students' fundamental mathematics competencies but was utilized as supporting data to explain the results of the quantitative analysis and to reinforce the interpretation of STEM learning implementation practices in Indonesia and Malaysia.

2.3.3. STEM Learning Observation Sheet

The observation of STEM instruction implementation was conducted by two experts through the analysis of video recordings of classroom instruction (video-based classroom observation) using the STEM Instruction Implementation Observation Sheet. This instrument was developed to assess the implementation of STEM instruction based on teacher activities during the mathematics learning process. The use of video recordings allowed researchers to conduct repeated observations, thereby enhancing the accuracy and consistency of the observation process.

The observation sheet contains eight indicators of STEM learning implementation, namely: (1) systematic implementation of STEM learning, (2) alignment of STEM projects with learning objectives, (3) assignment of tasks that encourage students to apply their knowledge and skills, (4) provision of constructive feedback, (5) the use of various forms of learning assessment, (6) the facilitation of students' active participation, (7) the facilitation of discussion and collaboration in solving STEM problems, and (8) providing students with opportunities to explore their interests and potential in STEM learning.

Each indicator was rated on a five-point scale (excellent, good, fair, poor, and very poor) with a description column to record key findings during the learning process. The observational data are used to describe the quality of STEM implementation in each school and serve as one source of data in the triangulation process, alongside teacher interview results, student questionnaires, and fundamental mathematics competency tests. The observational data were used to describe the implementation of STEM learning at each school and as part of the triangulation process alongside data from interviews, video recordings, student questionnaires, and fundamental mathematics competency tests.

2.3.4. Semi-Structured Interview

Semi-structured interviews were conducted with mathematics teachers to obtain more in-depth information regarding the implementation of STEM learning in the classroom. The interviews aimed to clarify the findings from video-based observations and to explore the teachers' experiences in designing, implementing, and evaluating STEM learning. The interview guidelines were developed based on several key aspects of STEM education implementation, namely: (1) the STEM integration model applied in instruction, (2) the characteristics of STEM projects assigned to students, (3) the learning objectives to be achieved, (4) compliance with occupational safety and health (OSH) standards during project implementation, (5) strategies for providing feedback to students, (6) forms of assessment used to measure learning outcomes, (7) challenges faced by students while completing STEM

projects, and (8) support from school facilities and infrastructure for the implementation of STEM education. All interviews were recorded, transcribed, and then analyzed using thematic coding to identify themes related to the implementation of STEM education, teaching strategies, challenges faced by teachers, and best practices for improving students' fundamental mathematics competencies.

2.4. Data Collection Procedure

Data collection was conducted simultaneously for both quantitative and qualitative data in accordance with a convergent mixed-methods design. Quantitative data were collected through a fundamental mathematics competency test and a questionnaire on students' perceptions of STEM instruction. The test was used to measure students' fundamental mathematics competencies, while the questionnaire was used to gather information about students' experiences and perceptions of STEM instruction.

Qualitative data were obtained through video-based classroom observations and semi-structured interviews with mathematics teachers. The data collection process began with recording all STEM learning activities in the classroom. The video recordings were then analyzed using an observation sheet for STEM learning implementation to identify teacher and student activities, learning strategies, classroom interactions, and the extent to which STEM learning characteristics were implemented. Subsequently, dialogues during the learning process were transcribed in stages to obtain a more detailed picture of the learning process and the development of students' mathematical competencies.

After the observation and transcription processes were completed, semi-structured interviews were conducted with teachers, both in person and online. The interviews aimed to clarify the observation findings, explore the learning strategies implemented, identify challenges encountered during STEM implementation, and gather information on best practices in STEM-based mathematics learning. All data obtained from tests, questionnaires, video-based observations, and interviews were subsequently analyzed separately according to the characteristics of each data set, then integrated during the interpretation stage to gain a comprehensive understanding of the implementation of STEM education and students' fundamental mathematics competencies in Indonesia and Malaysia.

2.5. Data Analysis

2.5.1. Quantitative Data Analysis

Quantitative data were analyzed using descriptive statistics to describe the profiles of students' fundamental mathematics competencies in each country. Next, a normality test was conducted using the Shapiro–Wilk test. Since the data did not meet the assumption of normality, the differences in fundamental mathematics competency between Indonesian and Malaysian students were analyzed using the Mann–Whitney U test at a 5% significance level. In addition to the significance value, this study also calculated the effect size (r) to determine the magnitude of the observed differences.

2.5.2. Qualitative Data Analysis

Data from observations, video recordings, interviews, and questionnaires were analyzed using Miles and Huberman's interactive analysis model, which consists of three stages: data reduction, data presentation, and drawing and verifying conclusions. Next, a coding process was conducted based on Hansen et al. (2022) approach by identifying key themes regarding the implementation of STEM learning, teachers' instructional strategies, student activities, implementation challenges, and best practices that emerged during the learning process.

2.5.3. Integration of Quantitative and Qualitative Findings

The final stage of the research is to integrate the results of the quantitative and qualitative analyses. The results of the statistical tests are used to determine whether or not there are differences in fundamental mathematics competencies between Indonesian and Malaysian students, while the results of observations, video recordings, interviews, and questionnaires are used to explain the factors that support or hinder the achievement of these competencies. The integration of these two types of data yields a more comprehensive interpretation of STEM instruction implementation while identifying best practices that can serve as recommendations for the development of mathematics instruction. The identification of best practices in this study uses national mathematics achievement scores based on the 2022 PISA as a contextual benchmark, rather than as a direct measure of classroom learning effectiveness. In PISA 2022, Indonesia scored 366 in mathematics, while Malaysia scored 409. Compared to the maximum PISA score of 579, these scores are equivalent to approximately 64% for Indonesia and 71% for Malaysia. Therefore, a STEM learning activity is identified as a best practice if the average achievement in FMC meets or exceeds that proportion, that is, at least 64% in the Indonesian context and at least 71% in the Malaysian context. This benchmark is used as a contextual reference to facilitate comparisons between the two countries and not as a universal standard for learning quality.

2.6. Trustworthiness and Ethical Considerations

The validity of the qualitative data was ensured through source triangulation and methodological triangulation, specifically by comparing the results of observations, video recordings, interviews, and questionnaires. In addition, the interview results were reconfirmed with the participants (member checking) to ensure that the researcher's interpretation aligned with the information provided. All participants were informed of the research objectives and voluntarily agreed to participate. The identities of the schools, teachers, and students were kept confidential, and all data were used solely for research purposes.

3. RESULTS AND DISCUSSION

3.1. Results

The results are presented based on the analysis of classroom learning videos, teacher interviews, and student reflection questionnaires to describe STEM implementation and identify best practices in mathematics classrooms in Indonesia and Malaysia. These findings

provide the empirical basis for comparing STEM learning practices between the two countries and examining their relationship with students' Fundamental Mathematical Competencies (FMC). The results are presented sequentially, beginning with classroom video observations, followed by teacher interview findings and student reflection questionnaire results. Table 2 summarizes the participants involved in each stage of data collection.

Table 2. Research respondents

No	Country	Learning Video	Questionnaire	Interview Student Reflection
1	Indonesia	School Teacher-1 (INA-1)	School Teacher-1 (INA-1)	32 students
		School Teacher-2 (INA-2)	School Teacher-2 (INA-2)	32 Students
2	Malaysia	School Teacher-1 (MLY-1)	School Teacher-1 (MLY-1)	28 Students
		School Teacher-2 (MLY-2)	School Teacher-2 (MLY-2)	23 Students

3.1.1. Learning Video Analysis

The classroom videos were analysed using a common observation framework to ensure consistency across the four classrooms. The analysis focused on four instructional aspects: the learning model implemented, the integration of STEM components into mathematics instruction, the use of digital technologies to support learning, and the assessment strategies used to evaluate students' understanding. These aspects provided the basis for comparing STEM implementation between Indonesia and Malaysia.

Learning Video of Teacher MLY-1

The observed lesson focused on geometric transformations, particularly the concept of reflection. Figure 1 presents selected screenshots from the observed classroom learning activities. Based on the classroom video, the lesson began with videos illustrating the role of reflection in telescope construction and the actual telescope manufacturing process, allowing students to connect mathematical concepts with real-world applications. Students then constructed a reflection plane, calculated the distance of an object from the line of reflection, and used GeoGebra animations to verify their predictions. The observed instructional sequence reflected the characteristics of STEM-integrated discovery learning by combining contextual exploration, mathematical investigation, and digital technology. The lesson concluded with a Quizizz assessment to evaluate students' conceptual understanding of reflection, providing immediate feedback on their learning outcomes.



Figure 1. Capture of learning video of teacher MLY-1

Learning Video of Teacher MLY-2

The observed lesson focused on statistics, particularly data distribution. Figure 2 presents selected screenshots illustrating students' data collection activities during the observed lesson. Based on the classroom video, the teacher implemented STEM-integrated project-based learning through collaborative data collection and analysis activities. In each group, students were tasked with measuring their weight, height, and travel time while climbing stairs. Students were also asked to measure the width of leaves collected from the school environment. The collected data were then organised and analysed to identify patterns in data distribution before each group presented its findings. To verify the accuracy of students' work, the teacher used statistical software. The lesson concluded with a Quizizz assessment to evaluate students' understanding of statistical concepts, providing immediate feedback on their learning outcomes.



Figure 2. Capture of learning video of teacher MLY-2

Learning Video of Teacher INA-1

The observed lesson focused on geometry, particularly flat-sided three-dimensional figures. Figure 3 presents selected screenshots illustrating students' collaborative design, construction, and testing activities during the observed lesson. Based on the classroom video, the lesson began with a contextual problem involving a café owner who wanted to design an aesthetically pleasing decorative lamp by combining at least three types of flat-sided three-dimensional figures. Students were also required to ensure that the lamp structure could protect the bulb when dropped from a height of 2.5 meters, introducing an engineering design challenge into the mathematical task. Next, students worked collaboratively in groups to develop and construct their designs using plastic pipettes to represent the geometric framework and a light bulb. Each group tested the durability of its design by dropping the decorative lamp from the specified height. The observed instructional sequence reflected the characteristics of

STEM-integrated project-based learning by integrating mathematical concepts with engineering design, collaborative problem solving, and iterative project testing.



Figure 3. Capture of learning video of teacher INA-1

Learning Video of Teacher INA-2

The observed lesson focused on number patterns, particularly arithmetic sequences. Figure 4 presents selected screenshots illustrating students' exploration of visual patterns and collaborative learning activities using the MatHub application. Based on the classroom video, the teacher implemented STEM-integrated project-based learning. At the beginning of the lesson, each group is asked to open the MatHub application, then read the worksheets there. Students were then instructed to observe visual patterns in pineapple skin, sunflower seeds, and other images presented in the worksheet to identify the underlying number patterns. These activities encouraged students to recognise mathematical patterns from real-world objects before formulating arithmetic sequence concepts. During the learning, each group presented its findings, followed by teacher feedback to verify the correctness of the proposed solutions. The lesson concluded with a quiz to evaluate students' understanding of arithmetic sequence concepts.



Figure 4. Capture of learning video of teacher INA-2

3.1.2. Analysis of Teacher Interview Results

To gain a deeper understanding of STEM teachers' teaching practices, the researcher conducted interviews with the four sample teachers, both online and offline. For Malaysian teachers, the interviews were conducted by the Malaysian research team, while for Indonesian teachers, the interviews were conducted by the Indonesian research team. Two Malaysian teachers were interviewed online, and one Indonesian teacher was interviewed both online and offline. Semi-structured interviews were conducted to clarify the results of video-based observations and explore teachers' experiences in designing, implementing, and evaluating learning. Interview guidelines were structured based on several key aspects as presented in the

Table 3. All interviews were recorded, transcribed, and then analyzed using thematic coding techniques to identify themes related to the implementation of STEM learning, learning strategies, challenges faced by teachers, and best practices in improving students' fundamental mathematical competencies. Table 3 summarises the interview results.

Table 3. Analysis of teacher interview results

No	Component	Teacher MLY-1	Teacher MLY-2	Teacher INA-1	Teacher INA-2
1	STEM integration forms	Integrated STEM (Discovery Learning)	Integrated STEM (Project-Based Learning)	Integrated STEM (Project-Based Learning)	Integrated STEM (Project-Based Learning)
2	The STEM project given	to calculate the distance of an object based on the reflection line (mirror position) and use GeoGebra to prove it.	Measuring weight, height, travel time when climbing stairs, and measuring the width of leaves and then calculating the size of the data distribution.	Creating decorative lamp designs from at least three types of flat-sided geometric frames, which do not break when dropped from a height of 2.5 meters.	Finding patterns from the arrangement of pineapple skin, patterns from the arrangement of sunflower seeds, and other images in LKPD.
3	Learning Material	Geometric Transformation (Reflection)	Statistics (Measure of Data Distribution)	Geometry (Flat-Sided Space Figures)	Number Patterns (Arithmetic Series)
4	Tools and materials used	All tools and materials meet *K3* standards	All tools and materials meet *K3* standards	All tools and materials meet *K3* standards	All tools and materials meet *K3* standards
5	Forms and Feedback given by teachers to students	3 forms of feedback, namely observation sheets, self-reflection and quizzes via quiziz.com	3 forms of feedback, namely observation sheets, self-reflection and quizzes via quiziz.com	verbal feedback related to projects, materials and verification of project results	2 forms of feedback, namely verbal feedback and quizzes.
6	Forms and objectives of assessment to measure student learning outcomes	Quizzes for final learning evaluations	Quizzes for final learning evaluations	Test the suitability of project results with the established standards	Quizzes for final learning evaluations
7	Difficulties experienced by students in completing projects	Students' diverse initial abilities affect the project completion process and	Time constraints Preparation of Learning Materials	Students' understanding of technology associated with math and science requires	Students' diverse initial abilities affect the project completion process and

No	Component	Teacher MLY-1	Teacher MLY-2	Teacher INA-1	Teacher INA-2
		student understanding Time constraints Students' technological literacy affects the understanding obtained	more, so that time for teaching is reduced Limited Facilities and Facilities. Projectors and other facilities in the classroom Rooms with complete facilities are not always available for all classes, so good scheduling is needed	a lot of time for relevant literacy Support from other teachers is quite difficult	student understanding difficulty applying knowledge (theory) into project form Rooms with complete facilities are not always available for all classes.
8	School facilities that support the implementation of STEM learning	1. Fast Internet Access 2. Gadget Usage Policy 3. Complete Technology Equipment 4. Technology Integration in Learning 5. Adequate Facilities	1. Availability of computers and LCDs 2. Classrooms equipped with AC 3. Support from the ICT team,	School facilities greatly support the implementation of STEM	1. Learning Facilities that Support Learning 2. The school supports the use of computers and projectors 3. the use of smartphones in learning
9	If the school does not provide facilities and infrastructure, the anticipation is that teachers do	Teachers must be more creative by using STEM learning with hands-on activities	Teachers must be creative and look for other facilities that can support learning	Teachers must look for other facilities that can support learning or provide their own facilities	Teachers are willing to look for other facilities that can support learning or provide their own facilities

From Table 3, it can be seen that the form of STEM used by teachers in mathematics learning, both in Indonesia and Malaysia, is integrated STEM, with learning models generally used, such as project-based learning and discovery learning. The projects given to students are quite diverse, with activities in and outside the classroom, and the subject matter is also diverse. Activities carried out in STEM projects can be hands-on or minds-on. The tools and materials used in implementing STEM have met the *K3* (Security, Safety, and Health)

standards. The feedback given by teachers to students generally takes three forms: observation sheets, oral feedback, and quizzes. The form and purpose of the assessments used by teachers are typically to measure student learning outcomes through final evaluations, quizzes/tests, or direct observation. The difficulties students in Malaysia and Indonesia experience in completing the assigned projects are generally due to varying initial abilities, which affect the project completion process and students' understanding. Time constraints are also an obstacle because preparing learning materials takes more time, reducing the time available for teaching. Limited facilities and other classroom resources are also obstacles. Rooms with complete facilities are not always available for all classes, so good scheduling is needed. This requires good cooperation between teachers and school administrators. Support from all elements of the school is a strength in implementing STEM learning. However, it was found that in some schools, support from other teachers was quite difficult. This illustrates that teachers' understanding of STEM is still diverse. If most teachers have realized the importance of implementing STEM in learning, then gradually, there will be a significant increase in student learning outcomes. Another strength is the support of facilities in schools that support the implementation of STEM learning, in addition to the support of other teachers. From the results of observations of learning videos, both Malaysian and Indonesian teachers found that fast internet access, gadget usage policies, complete technological equipment, availability of adequate facilities, comfortable study rooms and others are the main components supporting STEM learning. However, both Malaysian and Indonesian teachers stated that if the school does not provide facilities and infrastructure, the anticipation is that teachers will be creative in finding other facilities that can support learning or even provide their own facilities. This statement shows that both Indonesian and Malaysian teachers have a full awareness of improving student learning outcomes, especially through the implementation of STEM.

3.1.3. Analysis of Student Reflection Questionnaire Results

To examine students' perceptions of STEM learning and the learning experiences they gained during classroom instruction, students completed a self-reflection questionnaire. The questionnaire examined students' opinions about mathematics learning, the usefulness of STEM learning, project activities, challenges encountered during project completion, and the competencies they perceived to have developed through STEM instruction. Table 4 summarises the percentage of student responses for each questionnaire item and provides the basis for comparing students' perceptions between Indonesia and Malaysia.

Table 4. Percentage of student questionnaire answers

No	Statement	Malaysia			Indonesia		
		MLY-1	MLY-2	Average	INA-1	INA-2	Average
1	I like learning mathematics in class	74%	96%	85%	100%	94%	97%
2	Learning mathematics with STEM projects wastes a lot of time and is less useful	100%	100%	100%	91%	67.8%	79.4%

No	Statement	Malaysia			Indonesia		
		MLY-1	**MLY-2**	**Average**	**INA-1**	**INA-2**	**Average**
3	By working on projects, I can better understand the learning material	92.8%	100%	96.4%	96%	93.6%	94.8%
4	I have difficulty completing projects given by teachers	68%	83%	75.5%	45%	45%	45%
5	Learning mathematics with STEM makes me very curious about what is being learned	100%	91%	95.5%	96%	93%	94.5%
6	When working on a project, I always do the most important thing first	93%	96%	94.4%	82%	90%	86.2%
7	I check the project I am working on before submitting it to the teacher	89%	96%	92.6%	100%	97%	98.4%
8	I am used to making a to-do-list of work in sequence and in detail in completing the project given by the teacher	71%	74%	72.7%	73%	84%	78.5%
9	Studying math with STEM, made some of my skills develop						
	Creative	85.7%	73.91%	79.81%	64.0%	67.8%	65.9%
	Logical	82.1%	91.30%	86.72%	64.0%	64.5%	64.3%
	Innovative	67.9%	65.22%	66.54%	55.0%	58.1%	56.6%
	Problem Solving	82.1%	91.30%	86.72%	69.0%	61.3%	65.2%
	Collaboration	85.7%	86.96%	86.34%	72.0%	67.8%	69.9%
	Communication	82.1%	69.56%	75.85%	72.0%	80.6%	76.3%
	Using technology	89.3%	73.91%	81.60%	73.0%	61.3%	67.2%

Based on the data in Table 4, 74% of Malaysian students in School 1 and 96% of those in School 2 enjoy mathematics learning in class. In comparison, 100% of Indonesian students in School 1 and 94% of students in School 2 enjoy learning mathematics in class. If we look at the average, the percentage of Indonesian students who like learning mathematics is higher than that of Malaysian school students. For the statement that mathematics learning with STEM projects wastes a lot of time and is less useful, it turns out that 100 percent of Malaysian school students disagree with this. At the same time, Indonesian students who disagree are 79.4%. So, more Malaysian students think that STEM learning is useful.

Suppose we examine the percentage of students who agree that working on projects can help them better understand the learning material. It can be seen that Malaysian and Indonesian students share relatively similar opinions, with a similar percentage. Regarding the difficulty of completing projects, as reported by teachers, 75.5% of Malaysian students

disagree. In comparison, only 45% of Indonesian students disagree. This indicates that more Indonesian students struggle to complete projects. If we examine the percentage of students who agree with the statement that learning mathematics with STEM makes them very curious about what is being learned, it can be seen that Malaysian and Indonesian students share a relatively similar opinion, with similar percentages.

For the statement that when working on a project, they always work on the most important thing first, 94.4% of Malaysian students agreed. At the same time, 86.2% of Indonesian students agreed. This suggests that more Malaysian students prioritise the most important task first. For the statement "I check the project I work on before submitting it to the teacher", 92.6% of Malaysian students agreed. Meanwhile, 98.4% of Indonesian students agreed. This shows that more Indonesian students check their projects before submitting them.

For the statement "I am used to making a to-do list of work in sequence and detail in completing the project given by the teacher", 72.7% of Malaysian students agreed. Meanwhile, 78.5% of Indonesian students agreed. This shows that more Indonesian students make to-do lists of work in sequence and with detail.

In the statement "Learning mathematics with STEM makes several mathematical skills develop", the percentage of Malaysian students who agreed with most of the skills (creative, logical, innovative, problem solving, cooperation, and using technology) was higher than that of Indonesian students. Only in one skill, namely communication, did Indonesian students have a higher percentage.

3.1.4. Data Analysis of Students' Fundamental Mathematical Competencies Scores

Descriptive Analysis of Post-Test FMC

Students' Fundamental Mathematical Competencies (FMC) data were obtained from the post-test administered to each class in both Indonesia and Malaysia. Following the analysis of the post-test results for the instructional content delivered in each class, the students' FMC scores were summarized as presented in Table 5.

Table 5. Descriptive statistics of students' FMC

School	N	Mean	Lowest Score	Highest Score	Standard Deviation
(INA-1)	32	71.09	24	95	15.04
(INA-2)	32	80.63	47	100	14.93
(MLY-1)	28	81.25	49	98	11.51
(MLY-2)	23	77.56	34	93	13.13

As presented in Table 5, the descriptive statistics indicate variations in Fundamental Mathematical Competencies (FMC) across the four participating schools. Among the Indonesian schools, students in INA-2 achieved a higher mean score (80.63) than those in INA-1 (71.09), while demonstrating a slightly lower standard deviation (14.93 versus 15.04). This pattern indicates higher average achievement and marginally greater score consistency in INA-2 compared to INA-1. Individual scores in INA-1 spanned from 24 to 95, whereas INA-2 recorded a range from 47 to 100.

In the Malaysian sample, MLY-1 recorded the highest mean score (81.25) and the lowest standard deviation (11.51) among all four institutions. These metrics reflect both the

strongest average performance and the highest internal consistency within the sample. Conversely, MLY-2 yielded a lower mean score of 77.56 with a standard deviation of 13.13, alongside extreme scores ranging between 34 and 93. Across the entire dataset, MLY-1 demonstrated the highest overall mean score, whereas INA-1 recorded the lowest average achievement.

However, these results cannot describe the general abilities of Malaysian and Indonesian students. The comparative analysis between Indonesia and Malaysia using the Mann-Whitney U test shows that there is no statistically significant difference in students' Fundamental Mathematics Competence (FMC) between the Indonesian and Malaysian groups.

Normality Test of Fundamental Mathematical Competencies Data

Before conducting the comparative analysis to examine differences in students' Fundamental Mathematical Competencies (FMC) across countries and schools, the normality assumption was first assessed using the post-test scores. The normality test was conducted using the Shapiro-Wilk test for each individual class (INA-1, INA-2, MLY-1, and MLY-2) because the sample size in each class was less than 50 ($N < 50$). For the combined samples of Indonesian students and Malaysian students, the Kolmogorov-Smirnov test was used because the sample size exceeded 50 ($N > 50$). The results of the normality tests are presented in Table 6.

Table 6. Post-test FMC normality test results

Group	Test Statistic	df	Sig. (p-value)	Conclusion
INA-1	0.791	32	0.000	Not Normally Distributed
INA-2	0.936	32	0.059	Normally Distributed
Indonesia (Total)	0.135	64	0.005	Not Normally Distributed
MLY-1	0.891	28	0.007	Not Normally Distributed
MLY-2	0.813	23	0.001	Not Normally Distributed
Malaysia (Total)	0.213	51	0.000	Not Normally Distributed

As presented in Table 6, the combined Indonesian and Malaysian samples did not satisfy the normality assumption based on the Kolmogorov-Smirnov test. The Indonesian sample yielded a test statistic of 0.135 with a significance value of $p = 0.005$, while the Malaysian sample produced a test statistic of 0.213 with $p < 0.001$. These results indicate that the post-test scores for both countries were not normally distributed. Therefore, the subsequent comparison of students' Fundamental Mathematical Competencies (FMC) between the Indonesian and Malaysian groups was performed using the Mann-Whitney U test, which is appropriate for comparing two independent groups when the normality assumption is violated.

Comparative Analysis Between Indonesia and Malaysia

The Mann-Whitney U test was employed to determine whether there were statistically significant differences in students' Fundamental Mathematical Competencies (FMC) between

the Indonesian and Malaysian groups. The results of the comparative analysis are presented in Table 7.

Table 7. Mann-Whitney U-test results

Variable	Country	N	Mean Rank	p-value	Interpretation
FMC Score	Malaysia	51	64.42	0.065	No Significant Difference
	Indonesia	64	52.88		

As presented in Table 7, the Mann-Whitney U test revealed no statistically significant difference in students' Fundamental Mathematical Competency (FMC) between Indonesia and Malaysia ($p = 0.065 > 0.05$). Although Malaysian students obtained a higher average rank (64.42) than Indonesian students (52.88), this difference was not statistically significant. Based on the comparative analysis conducted, the observed variation in Fundamental Mathematical Competency (FMC) scores between the two groups did not show a significant difference. This confirms that the existing data variability is not strong enough to conclude that there is a superior mathematical performance of students from one country over the other. In other words, these empirical findings indicate that students from Indonesia and Malaysia essentially have relatively comparable levels of fundamental mathematical competency. The similarity in these competency profiles provides strategic methodological and practical implications for curriculum and pedagogical development in both countries. These results indicate that instructional models or mathematics learning interventions developed in one country have high transferability potential for application in another country. This means that the equivalence of basic competency levels opens up significant opportunities for the adoption, adaptation, and cross-country validation of proven effective mathematics learning models. Educational intervention policies designed in Indonesia can be tested for their effectiveness in the Malaysian school context, and vice versa, without being constrained by the extreme gap in prior knowledge at the basic level of student competency. We can apply this kind of research, as Yang et al. (2025) suggests, that there are four main themes for categorizing cross-country comparative studies: curriculum/textbooks, student learning, classroom practices, and teacher education.

Comparative Analysis by School Type

To provide a more detailed comparison, separate Mann-Whitney U tests were conducted for each school type by comparing students from public schools in Indonesia and Malaysia, and students from private schools in Indonesia and Malaysia. The results are presented in Table 8.

Table 8. Mann-Whitney U-test results by school type (public and private schools)

School Type	Country	N	Mean Rank	U	Z	p-value	Interpretation
Public Schools	Indonesia	32	29.27	327.50	-0.692	0.489	No Significant Difference
	Malaysia	23	26.64				

School Type	Country	N	Mean Rank	U	Z	p-value	Interpretation
Private School	Indonesia	32	23.80	233.50	-3.181	0.001	Significant Difference
	Malaysia	28	38.16				

As presented in Table 8, the Mann-Whitney U test shows there is no statistically significant difference in FMC scores between students from public schools in Indonesia and Malaysia (U = 327.50, Z = -0.692, p = 0.489). Although Indonesian students obtained a slightly higher average ranking (29.27) than Malaysian students (26.24), the difference was not statistically significant. In contrast, a statistically significant difference was found between students from top schools in Indonesia and Malaysia (U = 233.50, Z = -3.181, p = 0.001). Malaysian students achieved a higher average ranking (38.16) than Indonesian students (23.80). These findings indicate that differences in FMC performance between the two countries were mainly observed among students attending private schools, whereas students from mainstream schools demonstrated comparable levels of competency. The differences that occur in superior schools can be confirmed from Table 3, where both classes apply STEM to geometry material. However, there are differences in the use of learning media. MLY-1 school students in their learning use GeoGebra media for visualization, while INA-1 students use real objects for visualization. It is not certain that the differences in the use of different media are a factor that influences it. The level of complexity of geometric material and the need for visualization, and perhaps psychological factors could be the cause. For this reason, there needs to be a more in-depth study to find out what is causing it. This research provides opportunities for further research development.

3.2. Discussion

In this study, teaching practice was identified as a best practice only when it satisfied the predefined criteria established in the research framework. First, the implementation of the practice was associated with an average FMC score that reached or exceeded the contextual benchmark established for each country. Second, the practice was consistently observed during STEM learning implementation and was positively perceived by both teachers and students, as evidenced by classroom observations, questionnaire responses, and interview findings. Finally, the effectiveness of the practice was confirmed through the convergence of quantitative and qualitative evidence. Accordingly, the identified best practices represent evidence-informed instructional approaches supported by multiple sources of empirical data rather than routine teaching practices or general pedagogical recommendations.

The identified best practices contributed to higher FMC because they actively engaged students in applying mathematical ideas to meaningful tasks rather than merely completing routine exercises. Through project-based learning and discovery learning, students were required to interpret contextual problems, develop mathematical representations, test alternative solutions, and justify their reasoning during the learning process. This instructional pattern aligns with recent evidence identifying Project-Based Learning (PjBL) as one of the most widely adopted instructional designs in STEM-based mathematics education because it provides authentic learning experiences that connect mathematical concepts with real-world

problem solving (Widyastuti et al., 2026). The present findings extend this evidence by demonstrating that these learning experiences also supported higher FMC across different classroom contexts. The integration of digital technologies further strengthened this process by enabling students to visualize abstract mathematical concepts and verify their solutions more accurately. Therefore, the improvement in FMC appears to stem from students' sustained engagement in mathematical reasoning, representation, and problem solving throughout the learning process rather than from the instructional model itself.

One possible explanation for the variation in FMC scores among the Indonesian classrooms relates to differences in the mathematical content and instructional media employed during STEM implementation. As shown in Table 3, INA-1 focused on geometry through an engineering design project, whereas INA-2 implemented arithmetic sequences supported by the MatHub application. Geometry generally requires more complex spatial reasoning than arithmetic sequences, which may increase students' cognitive demands during problem solving. Consistent with this interpretation, Žilková et al. (2025) reported that students' responses to geometry tasks varied significantly according to task difficulty. In addition, the use of the MatHub application may have supported students' conceptual understanding and learning interest. Therefore, the observed difference between INA-1 and INA-2 is more likely to reflect differences in instructional content and learning support than differences in school facilities, especially because INA-1 had comparatively better facilities than INA-2. Nevertheless, this interpretation should be treated cautiously because the present study was not designed to isolate the effects of instructional content or digital media. Further studies are therefore needed to examine these factors using more controlled research designs.

Activities carried out in STEM projects support the integration of hands-on and minds-on activities. Such activities will make students more independent, easier to understand concepts, and reason scientifically. This is in line with van Eijck et al. (2025) who stated that a pedagogical approach that combines hands-on and minds-on activities supports students in developing conceptual understanding and scientific reasoning, as well as making students more independent in learning. This shows that the application of mathematical concepts to real-life situations affects student performance (Amo-Asante et al., 2025).

The difficulties experienced by students in Malaysia and Indonesia in completing the assigned projects are generally due to the diverse initial abilities of students, which affect the project completion process and student understanding. Students' prior mathematical understanding is a significant predictor for estimating students' problem-solving competencies (Djudin, 2023). Time constraints are also an obstacle, because preparing learning materials takes more time, so the time for teaching is reduced. Sevdinidis (2019) stated that the application of STEM in learning can take a long time, so effective time management, clear project objectives, and collaborative problem solving in groups are needed to make the process more effective and increase efficiency.

Limited facilities and other classroom resources are also obstacles. However, both Malaysian and Indonesian teachers stated that if the school does not provide facilities and infrastructure, their expectation is to be creative in finding alternative facilities that support learning or even offer their own facilities. This result is in line with Nga et al. (2025) who stated that teacher creativity is closely intertwined with pedagogical innovation and digital

integration, where institutional and time constraints are the main obstacles. This statement indicates that Indonesian and Malaysian teachers are well aware of the importance of improving student learning outcomes, particularly through the application of STEM.

Suppose we observe the results of the student reflection questionnaire. In that case, the average percentage of Indonesian students who like mathematics learning is greater than the average percentage of Malaysian school students, but more Malaysian students consider STEM learning to be useful. This is a country's strength in developing STEM for both countries, because most students enjoy learning mathematics with a STEM approach, as it is useful. This is proven again by the statements of students from both countries that, by working on projects, they can increasingly understand the learning material. Although many Indonesian students struggle to complete projects, most report that learning mathematics with STEM makes them very curious about the material. more Malaysian students do the most important things first, and more Indonesian students check their projects before they are submitted. In addition, more Indonesian students make a to-do list of work in sequence and detail. In this way, the stages of problem-solving and project work become more organised. The results show that STEM learning can increase students' enthusiasm and curiosity, train them in problem solving and work on projects in a more structured manner, so that their understanding of the subject matter increases. This is in line with Lademann et al. (2025) who stated that in STEM learning, the trend in performance and emotional responses is positive, while the cognitive load increases slightly.

To collect student opinions about increased abilities in STEM learning, the results show that the average percentage of Malaysian students who stated that their abilities (creative, logical, innovative, problem-solving, cooperative, and using technology) increased in STEM was higher than the average percentage of Indonesian students. The reasonably high percentage of their views on this increased ability illustrates the belief in higher student abilities. In comparison, Indonesian students whose percentage is higher than that of Malaysian students, are only in communication skills. However, if we examine the FMC test scores of students, it can be seen that the average abilities of Malaysian and Indonesian students are relatively similar.

Implementation of STEM in learning is a process of applying ideas, concepts, and concepts contained in meta disciplines through a series of activities to define and formulate solutions to authentic problems in the real world, which has been reported to improve students' thinking skills, affective aspects, and psychomotor in dealing with technological advances (Pertiwi et al., 2024; Syam et al., 2023; Winda & Dafit, 2021). High-quality integrated STEM learning provides meaningful learning experiences by engaging students in authentic problems that require the application of knowledge from multiple disciplines. Through integrated STEM practices, students can recognize the relevance of mathematics in real-world contexts and develop a deeper appreciation of how mathematical concepts are applied in everyday situations (Roberts et al., 2022). Concepts related to other disciplines in STEM make the problem-solving process very interesting, effective and efficient (Nurhikmayati, 2019). Katz-Buonincontro (2018) also stated that integration in STEM will provide new opportunities for students to engage in direct learning processes and produce products with creative and problem-solving abilities. AlAli et al. (2023) and Oschepkov et al. (2022), in their research,

stated that learning with the STEM approach is able to develop and improve students' abilities in logical, creative, innovative thinking, problem solving, and the ability to work together in a group in everyday life. Meanwhile, Stehle and Peters-Burton (2019) stated that the soft skills acquired by students through STEM learning include the ability to construct knowledge, solve real-world problems, self-regulation, effective communication, collaboration, and the ability to utilise information and communication technology in learning.

Observing the impact of STEM implementation on various abilities, as described above, reveals that STEM plays a crucial role in enhancing students' fundamental mathematical competencies. Fundamental mathematical competencies refer to the abilities that enable students to solve mathematical problems involving numbers, figures, formulas, and reasoning or logic (Schulz, 2024). To achieve optimal results from the implementation of STEM learning, it must be of high quality. Kennedy and Odell (2014) suggest that high-quality STEM implementation must include (a) integration of technology and engineering into science and mathematics; (b) prioritizing scientific inquiry and engineering design, including mathematics and science instruction; (c) collaborative approaches to learning, connecting students and educators with STEM; (d) Providing a global perspective and multiple perspectives; (e) Combining strategies such as project-based learning, providing formal and informal learning experiences; and (f) Incorporating appropriate technology to enhance learning.

An additional finding of this study emerged from the inferential statistical analysis of students' Fundamental Mathematical Competences (FMC). The results indicated a statistically significant difference in FMC between private schools in Indonesia and Malaysia. In contrast, no statistically significant difference was found between public schools in the two countries. However, these findings should be interpreted with caution because the study involved only one public school and one private school from each country. Consequently, the results cannot be generalized to represent all public and private schools in Indonesia and Malaysia. Nevertheless, these findings suggest the possibility of contextual differences between school sectors that warrant further investigation using larger and more representative samples to establish whether similar patterns are observed across broader educational settings.

4. CONCLUSION

The conclusion of this study is: (1) STEM practices in Indonesia and Malaysia are relatively the same, generally integrated STEM; (2) The process and results of STEM learning in relation to improving students' Fundamental Mathematical Competencies in Indonesia and Malaysia are relatively the same with relatively the same obstacles; (3) Best practices obtained from both countries include: a) The use of project-based learning and discovery learning models in STEM has succeeded in facilitating active learning through various projects, b) The combination of physical (hands-on) and mental (minds-on) activities in projects helps students understand concepts more deeply, c) Teachers must provide feedback in various forms to help students improve their understanding of the material and structured assessments to measure learning outcomes, d) Fast internet access, adequate gadgets, and the availability of other technological facilities are important factors that support the success of STEM learning in both countries. If there are limited facilities, teachers must be creative in utilizing alternative

facilities available to support learning. Based on the research results, several suggestions can be given, namely: (1) there needs to be further study related to the beliefs of students from both countries in STEM learning, considering that the results indicate differences in the self-confidence of students from both countries; (2) For other researchers who want to conduct the same research, it is recommended to research in a broader scale, considering that the current sample schools are only two schools from each country.

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REFERENCES

Abdurrahman, A. (2019). Developing STEM learning makerspace for fostering student's 21st century skills in the fourth industrial revolution era. *Journal of Physics: Conference Series*, *1155*(1), 012002. https://doi.org/10.1088/1742-6596/1155/1/012002

Adnan, M., Md Ibharim, L. F., Wong, Y. S., Yee, I. v., & Sukirman, S. (2025). Development and usability of a traditional game simulation module with augmented reality technology (AR-SiGaSTEM) in online learning to strengthen STEM skills among students. *LUMAT: International Journal on Math, Science and Technology Education*, *12*(4), 12. https://doi.org/10.31129/lumat.12.4.2226

AlAli, R., Alsoud, K., & Athamneh, F. (2023). Towards a sustainable future: Evaluating the ability of STEM-based teaching in achieving sustainable development goals in learning. *Sustainability*, *15*(16), 12542. https://doi.org/10.3390/su151612542

Amo-Asante, K., Arthur, Y. D., & Bonyah, E. (2025). Optimizing mathematics achievement through real-life contexts and historical insights: The moderating role of teaching and learning materials. *Educational Point*, *2*(1), e121. https://doi.org/10.71176/edup/16552

Arnab, S., Masters, A., Purnomo, R. A., Mahon, D., & Minoi, J.-L. (2025). Playful and frugal learning design: A value-based approach to inclusive and sustainable STEM education. *Social Sciences & Humanities Open*, *12*, 101923. https://doi.org/10.1016/j.ssaho.2025.101923

Atmojo, S. E., Lukitoaji, B. D., Rahmawati, R. D., Anggriani, M. D., & Anindya, A. P. (2025). Effects of hybrid STEM learning on 21st-century skills and character development in prospective elementary teachers: A mixed-methods study from Indonesia. *Qubahan Academic Journal*, *5*(2), 384–401. https://doi.org/10.48161/qaj.v5n2a1716

Benek, İ., & Akçay, B. (2022). The effects of socio-scientific STEM activities on 21st century skills of middle school students. *Participatory Educational Research*, *9*(2), 25–52. https://doi.org/10.17275/per.22.27.9.2

Dewi, N. R., & Maulida, N. F. (2023). The development of STEM-nuanced mathematics teaching materials to enhance students' mathematical literacy ability through information and communication technology-assisted preprospec learning model. *International Journal of Educational Methodology*, *9*(2), 409–421. https://doi.org/10.12973/ijem.9.2.409

Djudin, T. (2023). Transferring of mathematics knowledge into the physics learning to promote students' problem-solving skills. *International Journal of Instruction*, *16*(4), 231–246. https://doi.org/10.29333/iji.2023.16414a

English, L. D. (2023). Ways of thinking in STEM-based problem solving. *ZDM – Mathematics Education*, *55*(7), 1219–1230. https://doi.org/10.1007/s11858-023-01474-7

Erviana, N. F., Noer, S. H., & Triana, M. (2025). Implementation of STEM-integrated guided inquiry learning to improve students' mathematical communication skills. *Jurnal Pendidikan Matematika dan Sains*, *13*(1), 95–102. https://doi.org/10.21831/jpms.v13i1.83157

Fajrina, S., Lufri, L., & Ahda, Y. (2020). Science, technology, engineering, and mathematics (STEM) as a learning approach to improve 21st century skills: A review. *International Journal of Online and Biomedical Engineering (iJOE)*, *16*(7), 95–104. https://doi.org/10.3991/ijoe.v16i07.14101

Ferdiani, R. D., & Harianto, W. (2024). Honey and Mumford learning style: Creative thinking process in solving statistical problems. *International Journal of Evaluation and Research in Education (IJERE)*, *13*(1), 496–502. https://doi.org/10.11591/ijere.v13i1.25347

Ferdiansyah, F., Hastuti, N. S., & Widyastuti, W. (2025). Enhancing secondary students' mathematical creative thinking through STEM project-based learning. *Kalamatika: Jurnal Pendidikan Matematika*, *10*(1), 47–66. https://doi.org/10.22236/KALAMATIKA.vol10no1.2025pp47-66

Fitri, M., Yuanita, P., & Maimunah, M. (2020). Pengembangan perangkat pembelajaran matematika terintegrasi keterampilan abad 21 melalui penerapan model problem based learning (PBL) [Development of mathematics learning materials integrated with 21st-century skills through the implementation of the problem-based learning (PBL) model]. *Jurnal Gantang*, *5*(1), 77–85. https://doi.org/10.31629/jg.v5i1.1609

Forde, E. N., Robinson, L., Ellis, J. A., & Dare, E. A. (2023). Investigating the presence of mathematics and the levels of cognitively demanding mathematical tasks in integrated

STEM units. *Disciplinary and Interdisciplinary Science Education Research*, *5*(1), 3. https://doi.org/10.1186/s43031-022-00070-1

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International journal of STEM education*, *7*(1), 24. https://doi.org/10.1186/s40594-020-00225-4

Hansen, C., Steinmetz, H., & Block, J. (2022). How to conduct a meta-analysis in eight steps: a practical guide. *Management Review Quarterly*, *72*(1), 1–19. https://doi.org/10.1007/s11301-021-00247-4

Harisman, Y., Armiati, A., Suherman, S., Hafizatunnisa, H., Asra, A., Adnan, M., & Purnomo, Y. W. (2025). Integrated project-based learning (PIL) with STEM and ethnomathematics "Sipak Rago" and "Lari dan Beku" in junior high schools with bibliometric and experiments in junior high schools. *Salud, Ciencia y Tecnología*, *5*, 2090. https://doi.org/10.56294/saludcyt20252090

He, C. (2022). The effects of STEM education on mathematics, science, and English language development skills. *Journal of Education, Humanities and Social Sciences*, *6*, 220–228. https://doi.org/10.54097/ehss.v6i.4427

Hidayat, D., & Kastberg, S. (2025). Mathematical Modeling for Interdisciplinary STEM Problem-Solving. In *Indiana STEM Education Conference*, (pp. 13). https://doi.org/10.5703/1288284317830

Ibrahim, N., Mohamed, M., Seshaiyer, P., Rasid, N. S. M., Dalim, S. F., Salleh, M. F. M., Ismail, M. H., & Yusof, M. M. M. (2024). Enhancing prospectives educators' readiness through multidisciplinary collaboration in STEM education: An analysis of students enrolled in science and mathematics majors at a public university in Malaysia. *Asian Journal of University Education*, *20*(2), 303–315. https://doi.org/10.24191/ajue.v20i2.27000

Katz-Buonincontro, J. (2018). Gathering STE(A)M: Policy, curricular, and programmatic developments in arts-based science, technology, engineering, and mathematics education Introduction to the special issue of arts education policy review: STEAM Focus. *Arts Education Policy Review*, *119*(2), 73–76. https://doi.org/10.1080/10632913.2017.1407979

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science education international*, *25*(3), 246–258.

Lademann, J., Henze, J., & Becker-Genschow, S. (2025). Augmenting learning environments using AI custom chatbots: Effects on learning performance, cognitive load, and affective variables. *Physical Review Physics Education Research*, *21*(1), 010147. https://doi.org/10.1103/PhysRevPhysEducRes.21.010147

Malik, D. A. A., Yusof, Y., & Khalif, K. M. N. i. K. (2024). Determination STEM (mathematics) blended learning criteria via fuzzy AHP method. In *3rd International Conference On Applied & Industrial Mathematics and Statistics 2022 (ICoAIMS2022): Mathematics and Statistics Manifestation the Excellence of Civilization*, (Vol. 2895, pp. 060009). https://doi.org/10.1063/5.0192298

Masduki, M., Suwarsono, S., & Budiarto, M. T. (2019). Teacher's strategies to promote student's mathematical competencies in algebra: a case study. *Journal of Physics: Conference Series*, *1265*(1), 012016. https://doi.org/10.1088/1742-6596/1265/1/012016

McGunagle, D., & Zizka, L. (2020). Employability skills for 21st-century STEM students: the employers' perspective. *Higher Education, Skills and Work-Based Learning*, *10*(3), 591–606. https://doi.org/10.1108/heswbl-10-2019-0148

MeriSTEM. (2021). *Executive report on envisioning STEM education in Asia seminar: STEM leaders programme in Asia*. NIE.

Nasir, M. A., Talib, R., Latif, A. A., Hanid, M. F. A., & Harmeni, H. A. (2023). STEM productive learning of lower secondary school in Southern Zone, Malaysia. *International Journal of Learning, Teaching and Educational Research*, *22*(2), 281–301. https://doi.org/10.26803/ijlter.22.2.16

Nga, D. T., Thu, D. T. K., & Huyen, N. T. T. (2025). Comprehensive analysis of teachers' creativity based on Scopus data. *International Journal of Learning, Teaching and Educational Research*, *24*(9), 671–693. https://doi.org/10.26803/ijlter.24.9.33

Niss, M., & Højgaard, T. (2011). *Competencies and mathematical learning: Ideas and inspiration for the development of mathematics teaching and learning in Denmark*. Roskilde University.

Nugraha, M. G., Kidman, G., & Tan, H. (2026). Interdisciplinary thinking in STEM education: Insights from implementing the STEM-DTaM model with preservice teachers. *International Journal of Science and Mathematics Education*, *24*(6), 78. https://doi.org/10.1007/s10763-026-10703-w

Nurhayati, E., Mulyana, T., & Martadiputra, B. A. P. (2016). Penerapan scaffolding untuk pencapaian kemampuan pemecahan masalah matematis [The application of scaffolding for the attainment of mathematical problem-solving abilities]. *JP3M (Jurnal Penelitian Pendidikan dan Pengajaran Matematika)*, *2*(2), 107–112.

Nurhikmayati, I. (2019). Implementasi STEAM dalam pembelajaran matematika [Implementation of STEAM in mathematics instruction]. *Didactical Mathematics*, *1*(2), 41–50. https://doi.org/10.31949/dmj.v1i2.1508

OECD. (2019). *PISA 2018 results (Volume II): Where all students can succeed*. OECD Publishing. https://doi.org/10.1787/b5fd1b8f-en

Oschepkov, A. A., Kidinov, A. V., Babieva, N. S., Vrublevskiy, A. S., Egorova, E. V., & Zhdanov, S. P. (2022). STEM technology-based model helps create an educational environment for developing students' technical and creative thinking. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(5), em2110. https://doi.org/10.29333/ejmste/12033

Pertiwi, N. P., Saputro, S., Yamtinah, S., & Kamari, A. (2024). Enhancing critical thinking skills through STEM problem-based contextual learning: An integrated e-module education website with virtual experiments. *Journal of Baltic Science Education*, *23*(4), 739–766. https://doi.org/10.33225/jbse/24.23.739

Pramasdyahsari, A. S., Setyawati, R. D., Aini, S. N., Arum, J. P., Widodo, W., Astutik, I. D., Nusuki, U., Salamah, U., & Zuliah, N. (2024). Design digital book STEM-PjBL using context of kota Semarang: Learning media for stimulating students' mathematical literacy. In *Proceeding of the 7th National Conference on Mathematics and Mathematics Education (SENATIK)*, (Vol. 3046, pp. 020044). https://doi.org/10.1063/5.0194574

Prayogi, S., Bilad, M. R., Verawati, N. N. S. P., & Asy'ari, M. (2024). Inquiry vs. inquiry-creative: Emphasizing critical Thinking skills of prospective STEM teachers in the context of STEM learning in Indonesia. *Education Sciences*, *14*(6), 593. https://doi.org/10.3390/educsci14060593

Pujawan, I. G. N., & Suryawan, I. P. P. (2021). Effectiveness of STEM approach on mathematical communication ability. In *Proceedings of the 5th Asian Education Symposium 2020 (AES 2020)*, (pp. 368–372). https://doi.org/10.2991/assehr.k.210715.078

Raje, M. S., Tamilselvi, A., & Meenakshi, S. (2025). Innovative integration of numbers and letters in classroom activities: A design framework. *Journal of Engineering Education Transformations*, *38*(IS2), 567–573. https://doi.org/10.16920/jeet/2025/v38is2/25070

Rasyid, M. R. (2024). Integrating STEM approaches in algebra instruction to improve students' mathematical representation skills. *Aksioma Education Journal*, *1*(2), 21–32. https://doi.org/10.62872/tp357t12

Roberts, T., Maiorca, C., Jackson, C., & Mohr-Schroeder, M. (2022). Integrated STEM as problem-solving practices. *Investigations in Mathematics Learning*, *14*(1), 1–13. https://doi.org/10.1080/19477503.2021.2024721

Sarı, U., Alıcı, M., & Şen, Ö. F. (2018). The effect of STEM instruction on attitude, career perception and career interest in a problem-based learning environment and student opinions. *The Electronic Journal for Research in Science & Mathematics Education*, *22*(1), 1–21.

Sari, Y. M., El Milla, Y. I., Fiangga, S., Roqobih, F. D., Rosyidi, A. H., & Shahrill, M. (2025). STEM challenges in assessment scale: A content validity study for prospective teachers' readiness in sustainable STEM education. *E3S Web of Conferences*, *640*, 02008. https://doi.org/10.1051/e3sconf/202564002008

Schulz, A. (2024). Assessing student teachers' procedural fluency and strategic competence in operating and mathematizing with natural and rational numbers. *Journal of Mathematics Teacher Education*, *27*(6), 981–1008. https://doi.org/10.1007/s10857-023-09590-7

Senawati, A., Noer, S. H., & Wijaya, A. P. (2025). The implementation of STEM-integrated problem-based learning to improve students' mathematical reasoning ability. *JP2M (Jurnal Pendidikan dan Pembelajaran Matematika)*, *11*(2), 997–1005. https://doi.org/10.29100/jp2m.v11i2.7575

Sevdinidis, M. (2019). STEM application with the PBL method for the design and construction of a humanoid head that detects the brightest point of its environment and turns itself to that. In *10th Jubilee International Conference of the Balkan Physical Union*, (Vol. 2075, pp. 200013). https://doi.org/10.1063/1.5091438

Sharma, P. (2021). Importance and application of mathematics in everyday life. *International Journal for Research in Applied Science and Engineering Technology*, *9*(11), 868–879. https://doi.org/10.22214/ijraset.2021.38869

Srikoon, S., Khamput, C., & Punsrigate, K. (2024). Effects of 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

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st century skills in selected exemplary inclusive STEM high schools. *International journal of STEM education*, *6*(1), 39. https://doi.org/10.1186/s40594-019-0192-1

Suherman, S., Vidákovich, T., Mujib, M., Hidayatulloh, H., Andari, T., & Susanti, V. D. (2025). The role of STEM teaching in education: An empirical study to enhance creativity and computational thinking. *Journal of Intelligence*, *13*(7), 88. https://doi.org/10.3390/jintelligence13070088

Sukmawati, W., Maarif, S., Burhendi, F. C. A., Kadir, K. A., Jamaludin, N. B., Shaari, H., & Adlawan, H. A. (2026). Teachers' readiness and perceptions of augmented reality for sustainable STEM education. *AMPLITUDO : Journal of Science and Technology Innovation*, *5*(1), 53–66. https://doi.org/10.56566/amplitudo.v5i1.505

Syam, H., Rahayuningsih, S., & Muzaini, M. (2023). Implementasi STEM project based learning: Mengeksplorasi domain kognitif dan afektif dalam pembelajaran matematika [Implementation of STEM project-based learning: Exploring cognitive and affective domains in mathematics education]. *Jurnal Riset dan Inovasi Pembelajaran*, *3*(3), 274–288. https://doi.org/10.51574/jrip.v3i3.1246

Taylor, P. C. (2016). Why is a STEAM curriculum perspective crucial to the 21st century? In *14th Annual conference of the Australian Council for Educational Research*, (pp. 89–93).

van Eijck, T., Bredeweg, B., Holt, J., Pijls, M., Bouwer, A., Hotze, A., Louman, E., Ouchchahd, A., & Sprinkhuizen, M. (2025). Combining hands-on and minds-on learning with interactive diagrams in primary science education. *International Journal of Science Education*, *47*(18), 2413–2433. https://doi.org/10.1080/09500693.2024.2387225

Widyastuti, W., Muhaimin, L. H., Turmudi, T., Suryadi, D., & Hattamurrahman, M. P. S. (2026). Mathematics learning design in STEM: A systematic literature review. In *ETLTC2025 International Conference Series: Technology and Smart Society*, (Vol. 3432, pp. 020016). https://doi.org/10.1063/5.0328311

Winda, R., & Dafit, F. (2021). Analisis kesulitan guru dalam penggunaan media pembelajaran online di sekolah dasar [An analysis of the difficulties faced by teachers in using online learning media in elementary schools]. *Jurnal Pedagogi Dan Pembelajaran*, *4*(2), 211–221. https://doi.org/10.23887/jp2.v4i2.38941

Xu, C., Di Lonardo Burr, S., & LeFevre, J.-A. (2023). The hierarchical relations among mathematical competencies: From fundamental numeracy to complex mathematical skills. *Canadian Journal of Experimental Psychology / Revue canadienne de psychologie expérimentale*, *77*(4), 284–295. https://doi.org/10.1037/cep0000311

Yang, X., Chan, M. C. E., Kaur, B., Deng, J., Luo, J., & Wen, Y. (2025). International comparative studies in mathematics education: a scoping review of the literature from 2014 to 2023. *ZDM – Mathematics Education*, *57*(4), 745–761. https://doi.org/10.1007/s11858-025-01700-4

Yusoff, N., & Ahmad, N. J. (2025). The implementation of interdisciplinary STEM project-based learning (Pjbl) in Malaysian primary school. *Journal of Sustainability Science and Management*, *20*(10), 2163–2180. https://doi.org/10.46754/jssm.2025.10.010

Zahir, N. Z. M., Hashim, S., Rahman, K. A. A., Zulkifli, N. N., Riyadi, S., & Siswantoro, J. (2024). Unveiling effective CSCL constructs for STEM education in Malaysia and

Indonesia. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *46*(1), 97–106. https://doi.org/10.37934/araset.46.1.97106

Žilková, K., Záhorec, J., & Munk, M. (2025). Analysis of the level of geometric thinking of pupils in Slovakia. *Education Sciences*, *15*(8), 1020. https://doi.org/10.3390/educsci15081020