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Elementary School Teachers' Skills in Integrating STEM Education

[1]Nur Choiro Siregar, [2]Warsito, [3]Roslinda Rosli, [2]Desty Haswati, [4]Aris Gumilar
[1]Department of Informatics Engineering, Universitas Muhammadiyah Tangerang, Indonesia
[2]Department of Mathematic Education, Universitas Muhammadiyah Tangerang, Indonesia
[3]Research Center of STEM Enculturation, Faculty of Education, National University of Malaysia, Malaysia
[4]Management, Universitas Muhammadiyah Tangerang, Indonesia
[1]nur.choiro@umt.ac.id

Abstract

Integrating science, technology, engineering, and mathematics (STEM) education is the principal capital to improve the nation's economic dignity. Students' STEM abilities must be different from the role of teachers as facilitators in the learning process at school. The ability of elementary school teachers to apply STEM approaches is critical, especially in mathematics and natural sciences (IPA) studies. The study aims to identify how elementary school teachers are integrating STEM approaches. We used a qualitative case study research method, conducting in-depth interviews with two math teachers and two science teachers from the city and the village. The findings suggest differences in teachers' ability to apply STEM approaches during classroom instruction. Three aspects affect this difference: (1) lack of teacher professional development (training, seminars, or workshops); (2) facilities for obtaining information (equipment such as laboratories and computers); and (3) different abilities of students (intellectual intelligence). There are differences in the ability of teachers in urban and rural areas to implement STEM approaches. Teachers who teach in villages have limited knowledge of integrated STEM; internal and external factors greatly influence the differences. Therefore, policymakers must undertake more programs and activities to develop their ability to implement STEM approaches. We suggest further research to explore the factors that affect teachers' ability to integrate STEM. We discuss the limitations and implications of this study.

Keywords: STEM Approach, Teacher skills, Primary school, Learning, Facilitator

Introduction

Integrating STEM education is one of the learning process approaches that can help improve the learning process from elementary school to tertiary level, especially in four disciplines simultaneously, namely science, technology, engineering, and mathematics (Siregar et al., 2019). STEM education significantly improves students' thinking skills, understanding of subject matter, analyzing, creating, practicing group work, critical thinking, taking the initiative, communication skills, and digital skills (Nguyen, 2019; What is STEM? 2020). In addition, STEM integration helps foster students' skills to create and be economically competitive globally (Siregar et al., 2023). According to Siregar et al. (2019), integrating STEM education can build students' awareness that mastering these four disciplines is essential. STEM integration helps prepare students for careers in the 21st century.

STEM integration combines theory and practice simultaneously in four disciplines (Zhou et al., 2022). The combination of science, technology, engineering, and mathematics theory can be practiced and connected to students' real lives (Siregar et al., 2022). Therefore, teachers need

to integrate STEM into the curriculum and have various STEM pedagogic skills to be applied in classroom teaching practices.

According to Thibaut et al. (2019), elementary school teachers need a deep understanding of STEM content. Mateos-Núñez et al. (2020) said that teachers are encouraged to use a discovery approach in the learning process with the integration of STEM education. In addition, teachers can use the project learning process. The project learning process can build students' confidence because each student is involved in the learning process (Soybean et al., 2022).

One of the best supporters that teachers must have when intending to pursue STEM education is the ability to use technology. Most teachers with the ability and technology training prefer integrating STEM education into their teaching process (Bakar et al., 2020; Siregar & Anggrayni, 2023). In addition, teachers must be creative and innovative in managing the classroom in applying STEM education so that students are actively involved in the learning process (Adhelacahya et al., 2023; Siregar et al., 2019).

The ability of teachers to collaborate with fellow teachers and other members of the profession can help realize the effective integration of STEM education. Dung et al. (2020) suggested that teachers' collaboration skills between colleagues and professional members can affect student achievement in STEM education. The integration of STEM helps teachers introduce and teach students how to build communication with various components well, namely between school institutions, community groups including students' parents, and business activists (Burton et al., 2022; Felder & Brent, 2016; Manokarn & Chamrat, 2022; Patel, 2024). Flexibility and cultural elements are two things that positively impact the implementation of STEM integration during the learning process (O'Leary et al., 2020; Widowati et al. (2021). In addition, another factor is the ability of teachers to effectively select and make assessments of the student learning process (Martín-Páez et al., 2019).

VanTassel-Baska and Wood (2010) suggest how teachers can apply these four disciplines to learning. First, teachers must understand the nature of integrating multidisciplinary science. Integrating these four sciences focuses on applying separate learning subjects taught by each teacher in the field of study. Teachers should understand that each learning topic includes techniques in the subject matter to learn and discuss, as each subject has unique achievement metrics. However, we can apply and relate these topics to real-life situations, thus gaining practical knowledge. Second, teachers should organize meetings, create programs related to topics in general, and discuss how to relate those topics to students' real-life experiences. Third, teachers understand the essence of cross-subject integration.

Some schools only focus on delivering subject matter using a particular (conventional) approach (Bakker et al., 2022; Supriani et al., 2022). Therefore, the learning process tends to emphasize theory rather than practical application, lack of integration of theory and practice, and Less emphasis on group learning (Lee & Perret, 2022). However, the learning process with STEM integration is different, namely building a direct relationship between the learning process and the world of work. Teachers teach material based on actual practice. They were equipping students with operational skills, especially in problem-solving. Teachers emphasize and ensure that students not only focus on knowledge but also apply the knowledge they have to the materials they learn. Teachers encourage every student to be actively involved and independent and initiate every assignment given. Teachers practice students' communication,

teamwork, critical thinking, discovery, and problem-solving skills directly in the learning process (Siregar & Anggrayni, 2023).

In various developed and developing countries, many groups have introduced STEM education early, hoping that students will be interested and choose a career in STEM fields. Ultimately, it will contribute to building the economy in a better direction (Martín-Páez et al., 2019). However, STEM education, especially for elementary school teachers in urban and regional areas, is still relatively new in Indonesia. Therefore, most elementary school teachers need help to know/know how to integrate STEM. So far, many teachers have only focused on teaching theory rather than practice. STEM integration requires teachers to have the skills to master four disciplines at once in classroom learning practices (Rahman et al., 2022). This research identifies how elementary school teachers integrate STEM approaches in urban and rural areas.

Method

This research uses a qualitative approach. We carried out the implementation from January to July 2022. We use two data sources to address the focus of the problem: primary data and secondary data. The main data was the results of a 90-minute online interview with four elementary school teachers from rural and urban. The respondents were four elementary school math and science teachers who teach in urban and rural areas. The online interviews included insights from four elementary school teachers focused on their ability to integrate STEM education. Specific aspects of the data collected were educational background, teaching experience, STEM knowledge and application, professional development, barriers and challenges, and geographic impact.

The criteria for selecting respondents are as follows: (a) teachers have a history of undergraduate education in the fields of mathematics education and natural science education (IPA); (b) have at least ten years of experience teaching mathematics and science in elementary schools; (c) possess substantial knowledge and understanding of STEM education, including its principles, interdisciplinary approach, and application in the classroom; (d) have attended national/international seminars related to STEM; (e) teaching in the Bogor city; and (f) teaching in the Kalimantan region.

Four teachers from Bogor City and four respondents from the Kalimantan region were involved. The following is a description of the respondents to this study. Urban mathematics teacher (GMK). GMK teachers obtained a bachelor's degree in mathematics education. Although GMK has a bachelor's degree in mathematics, he teaches 6th-grade science in elementary school. GMK has gained experience teaching students with higher abilities, especially those in superior classes. GMK has 12 years of teaching experience.

Rural mathematics teacher (GMD). Teacher, GMD, is a math teacher with a bachelor's degree in math education. Not only did she teach math subjects in school, but she also taught science subjects in 6th grade elementary school. GMD has ten years of teaching experience. According to GMD's experience, it teaches students with moderate to lower abilities (meaning they have low intelligence). He often explains math and science subjects by repeating them until students understand.

Urban science teacher (GSK). GSK teachers have a degree in biology education. Although he has a degree in biology, he also teaches mathematics in elementary school. He has 15 years of teaching experience. He had previously taught students with a reasonable level of intelligence, so he found it easy to teach students in this class. Prior to transitioning to teaching in sixth grade, she served as a fourth-grade elementary school teacher.

Rural science teacher (GSD): An elementary school teacher with a biology education degree. In addition to teaching science, he also teaches mathematics at the sixth-grade level. He has been teaching for 13 years. He teaches students with moderate to low levels of intelligence. He often needs help delivering math and science material because many students need more preparation time.

We obtained secondary data from online observations. Observations were conducted three times (January 3, April 4, and July 4 2022) via zoom to evaluate the consistency of the learning process implemented by teachers in the classroom. The observed data focused on how STEM components were integrated into teaching practices, exploration of science principles to understand natural phenomena, use of technology as a teaching tool, application of engineering concepts in problem-solving activities, and application of mathematical concepts in data analysis. In addition, classroom interaction patterns, student engagement levels, and the effectiveness of teaching strategies were carefully documented. Four indicators serve as a benchmark for the accuracy of the data collected. The four indicators in question are (1) science, (2) technology, (3) engineering, and (4) mathematics. The data analysis techniques used were synthesis and coding. First, we analyze and theme the draft interview results to produce a theme that addresses the focus of the research problem. The next step involves comparing the results of the interview with observations. Figure 1 summarizes this study's components and requirements (Coccia, 2020).

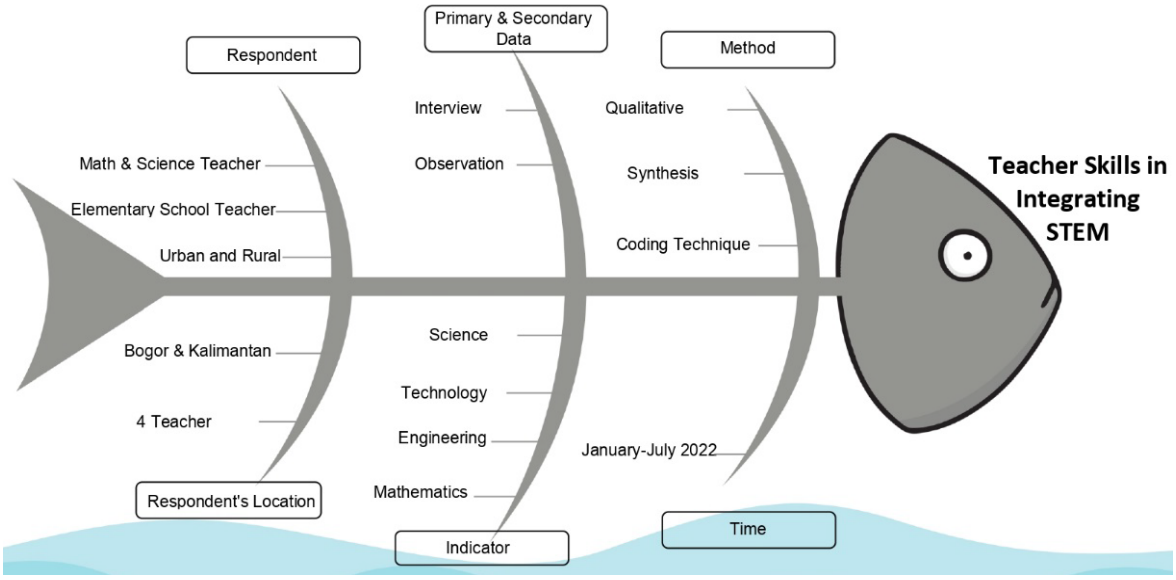

Figure 1. Fishbone research.

Results and Discussion

Integrating STEM education is an interdisciplinary approach to teaching and learning, emphasizing critical thinking, problem-solving, and innovation. The role of elementary school teachers is crucial to preparing students for future careers in STEM fields. Therefore, elementary school teachers must have practical STEM integration skills in classroom learning. STEM education is one of the educational solutions that prepares students' ability to connect theory and practice at the same time. This integration capability aims to maintain the scientific, technical, and competitive position in the global economy in developing countries (Xinh & Van Hong, 2021).

The importance of integration in STEM subjects has forced primary school teachers to reform their classroom content and teaching methods, especially in the study of mathematics and IPA. The results of online interviews and observations showed differences in teachers' ability to apply STEM integration approaches during classroom teaching. This issue can lead to an inconsistent teaching experience for students, thus affecting their understanding of and interest in STEM subjects.

The synthesis results relate to the differentiation of STEM integration in mathematics and science teachers in the cities of Bogor and Kalimantan. There needs to be more professional development opportunities for teachers, and there is a lack of information collection facilities and disparity in students' abilities, especially in mathematics and science.

Professional development (PD) programs can assist teachers in learning how to effectively integrate all four disciplines, such as combining science with engineering, technology, and mathematics (for example, creating mineral water), a product that people often consume daily. Teacher professional development can take many forms, such as workshops, seminars, online courses, or conferences. Such opportunities provide teachers with the skills, knowledge, and confidence necessary to integrate STEM education into their teaching practices (Dung et al., 2020).

Continuous professional development is essential for primary school teachers to stay up-to-date with the latest teaching strategies and technologies. Thibaut et al. (2019) suggested that elementary school teachers could benefit from continuous professional development in STEM education to improve their teaching skills. Teachers who receive continuous professional development are more likely to be effective in integrating STEM education into their teaching practices.

Felder and Brent (2016) highlight the importance of teacher collaboration in professional development. Collaborative professional development activities such as lesson studies, peer training, and teacher networking allow teachers to discuss and reflect on their teaching practices and share their experiences and knowledge with others. These activities can also foster a culture of continuous improvement and innovation among teachers, leading to the development of effective STEM education practices.

Bakar et al. (2020) propose tailoring professional development activities to the unique needs of primary school teachers. For example, professional development activities should provide teachers with practical and hands-on experience in integrating STEM education into their teaching practices. Teachers should align professional development activities with the school's

curriculum and goals, allowing them to collaborate with their peers to develop effective STEM education strategies.

In addition to professional development opportunities, elementary school teachers can benefit from access to teaching resources and materials that support integrating STEM education into their teaching practices. Adhelacahya et al. (2023) suggest that these resources and materials should be accessible, flexible, and adaptable to meet the diverse needs of elementary school teachers. Teaching resources and materials can include STEM curriculum, lesson plans, textbooks, online resources, and other learning materials.

The full support of school administrators and policymakers influences the success of STEM integration by teachers. Widowati et al. (2021) emphasize that school administrators must provide a supportive environment that encourages teachers to innovate and experiment with new teaching strategies. School administrators must also provide teachers with the necessary resources and support to implement STEM education effectively. Policymakers can also play an essential role in promoting the integration of STEM education in elementary schools by providing funding for professional development activities, teaching resources, and materials.

O'Leary et al. (2020) highlight the indispensable role of parents and the community in implementing STEM education. Parents and the wider community can provide valuable resources and expertise to enrich the student learning experience. Schools can engage parents and the broader community through various activities, such as science fairs, STEM workshops, and community outreach programs.

Teachers' lack of professional development is characterized by two indicators: (1) how to combine the four disciplines and (2) the barriers to combining the four disciplines. With continuous professional development, teachers may have the pedagogical strategies and up-to-date content knowledge necessary to teach STEM subjects effectively.

The first indicator is: How are teachers integrating STEM disciplines into learning? Based on the results of interviews and observations, teachers introduce each of the four subjects separately to achieve the school curriculum targets that have been determined according to the syllabus. In addition, teachers theoretically know each subject but still need help to combine them into a single topic. The following results are based on interview citations from four GMK, GMD, GSK, and GSD teachers.

> *Teachers need help implementing STEM education in the learning process because we are more concerned with achieving the targets set by the school. The provisions in question refer to the competency standards of mathematics and science subjects. Therefore, teachers need additional time to implement the STEM curriculum effectively. In addition, teachers must still acquire the necessary skills to integrate these four sciences easily into a single topic. In theory, teachers have this knowledge, but their practical application still needs to be improved. Therefore, before integrating STEM into learning, teachers must receive guidance. The guidance in question can be through training, seminars, or workshops, all of which can provide guidance.*

GMD and GSD added, "*The government pays less attention to teachers in rural areas, which causes education to lag in urban areas*." The observation results show that the city's learning process involves students more actively than rural students. On the contrary, teachers dominate the learning process in the regions. As a result, student involvement is less visible in solving problems, especially in math subjects. Previous research has shown that schools should implement PD programs, especially in STEM education. This program trains teachers to apply

problem-solving skills according to the natural context, making it easier for students to understand the learning material. PD programs can provide a STEM education model and integrate theory into practice through problem-solving activities that contextualize real life (Avery & Reeve, 2013; Rosli & Siregar, 2022).

The second indicator is: What are the barriers to implementing a STEM blend in the teaching process? There are several obstacles for teachers in implementing STEM education, including standards-based workloads. Teachers do not have enough time to implement STEM education because of the limited time teachers have to teach one subject. Teachers still need comprehensive assessment standards for STEM education. Teachers acknowledge that they must learn to meet these needs. Teachers have suggested that policymakers create training programs or seminars so that teachers can gain a more comprehensive experience to help them implement STEM education in schools. There is a need for teachers to have access to tools that facilitate the implementation of STEM education.

In addition, the school's facilities are limited. The school needs to facilitate the availability of tools for teachers who want to teach mathematics and science, so teachers can only make props, such as a minor planet Earth (science subject). The means needed by teachers to teach material are telescopes or binoculars. However, the teachers cannot fulfill their responsibilities due to financial limitations, so the material presented is limited to theory and needs more practical application.

School and education stakeholders need to further introduce STEM education through courses, training, and seminars, as teachers rely solely on their educational backgrounds and each other's knowledge to get help. Teachers admitted they were not proficient in integrating engineering into math, science, and technology subjects, so they needed a place to facilitate sharing and learning from experts. City teachers have greater access to STEM education training than rural teachers. As a result, there is still an imbalance in the ability of teachers who teach in cities and villages to apply STEM approaches. These gaps can result in unequal educational opportunities for students based on their geographic location, potentially widening the educational gap between urban and rural areas.

Based on the observation results, village teachers need more knowledge of STEM integration than in cities. The GSK teacher revealed that he uses the laboratory to teach the solar system. In contrast, GSD teachers only take advantage of school facilities if they are available. Nevertheless, GSD teachers strive to teach material using simple teaching aids tailored to the teacher's ability—access to essential teaching resources, such as laboratories, computers, and other technological devices. The implication is that teachers who need adequate access to these resources will need help to provide students with a hands-on learning experience.

Every student has a diverse level of intellectual ability by nature. Students' intellectual abilities influence them to understand STEM concepts. Therefore, teachers need to differentiate their teaching to meet the various needs of students. Without adequate support and resources from schools, this problem becomes a challenge for teachers in the teaching process. In the end, the test results given by the teacher as a benchmark produce very different results for each student. Interviews with GMK, GMD, GSK, and GSD teachers reveal this.

> *Students demonstrate learning success when they respond to questions orally and in writing. We ask verbal questions during the learning process in the classroom. Written*

questions come from the final evaluation results in each learning session, quiz, midterm, and final semester exam.

Students' intellectual abilities influence teachers when implementing STEM education in the learning process. GMK and GMD teachers found that they have not fully implemented STEM education in the classroom, even though students can understand what the teacher is explaining. Students' environment, including their family and surrounding conditions, also affects their intelligence abilities. However, this differs from the recognition by GSK and GSD that teachers cannot implement STEM education due to the limitations of their students' intellectual abilities.

GSK and GSD teachers revealed that to complete a subject, teachers must explain the related material several times because students must understand how to carry out the learning process beforehand. Many students studying here come from low- to middle-income backgrounds. As a result, their parents are unable to help them learn. Their parents need help buying cell phones or bringing their children for extra learning outside school. Even their parents admit that their ability to meet their basic food needs could be improved, which is why the teachers here cannot force their students to attend additional lessons, especially in math. So, the only source of student reference here is the teacher's explanation, even though the school provides a student handbook. However, students need help to study these books thoroughly at home.

Conclusion

Based on the objectives of this study, it can be concluded that teachers cannot universally implement STEM learning for all students in every situation. Several significant factors affect the feasibility and effectiveness of STEM integration, including insufficient professional development opportunities, limited access to facilities and resources, and differences in students' intellectual abilities.

In addition, to the teacher's educational background, the skill factor of managing the learning process with the integration of STEM in the classroom is very necessary for a teacher who teaches in urban areas and regions. STEM integration skills can be bridged by additional training programs or activities provided to teachers. Policymakers should facilitate programs/activities such as seminars for teachers related to STEM integration. In reality, teachers in cities and villages must be more experienced in integrating STEM education into learning. The Ministry of Education should carry out socialization and learning components such as the STEM integration curriculum at the elementary that every teacher in Indonesia can access.

Primary school teachers must be provided with activities or programs that sustainably develop their profession, such as access to STEM-based teaching materials and full support from all parties involved especially policymakers. In addition, effective STEM education practices require a collaborative and innovative learning environment among teachers, parents, and the wider community to equip students with skills for the 21st century.

This study has provided suggestions and recommendations, but many limitations must be examined. There are three limitations in this study. First, the study focused on primary school teachers in the cities of Bogor and Kalimantan, thus limiting the generalization of the findings to other contexts. Second, this research is based on self-reported teacher data, so there will be

social bias. Third, the study reviewed did not examine the impact of STEM education on student achievement and career interests.

The research implications are devoted to three aspects for policymakers, school administrators, and elementary school teachers. First, policymakers should prioritize funding for sustainable professional development opportunities for primary school teachers in STEM education both in cities and villages. It includes workshops, seminars, online courses, and conferences, which provide teachers with the skills, knowledge, and confidence necessary to integrate STEM education into their teaching practices. Second, school administrators must provide a supportive environment, encourage teachers to experiment with new teaching strategies, and collaborate with their peers to develop effective STEM education practices. It includes providing access to teaching resources and materials that support integrating STEM education into teaching practice. Third, elementary school teachers must embrace the principles of STEM education and develop the skills and knowledge necessary to integrate STEM education into their teaching practices.

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