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STEM Highlights: Principles, Frameworks, and Implementation Strategies in Improving Scientific Literacy

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Abstract

The 21st-century era, marked by the rapid development of information technology, requires students to be adaptive and have several skills that must be mastered to be able to compete in today's era. The important skills in the 21st century or so-called The 4C-skills consist of communication, collaboration, critical thinking, in general containing specific skills that need to be empowered in learning activities, such as problem-solving skills, critical thinking, communication skills, collaborating, innovation and creation, literacy, information metacognition, and various other skills. However, the reality in the field is based on the results of TIMSS and PISA, where this test measures the mathematics, science, and literacy skills of developed and developing countries, Indonesia's ranking is still in the lowest rank. The method used in this research is the literature study method, which examines the STEM principles, implementation strategies, and their prospects for improving scientific literacy skills. Based on the results, the success key while implementing STEM in the classroom is to prepare STEM educators with a conceptual understanding of the principles, frameworks, and strategies of integrated STEM implementation and learning theories from the four STEM fields. It should be integrated to increase the pedagogical skills and to mastery the technology as a learning support. Also, the development of professional experience for teachers in implementing STEM in various cross-materials is needed to provide a strong conceptual framework of an integrated STEM approach and build their confidence in teaching an integrated STEM approach. Hopefully, this article can provide a comprehensive overview of improving scientific literacy as one of the keys to improving the quality of quality education in Indonesia.

Keywords: Literature study, Scientific literacy, STEM

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INTRODUCTION

Industrial Revolution 4.0 is a term that refers to the trend of automation and data exchange systems in a structured, automatic, and integrated online network. The industrial revolution 4.0 was first initiated by Professor Klaus Schwab, a well-known German economist quoted in his book: The Fourth Industrial Revolution, which revealed that the concept of the industrial revolution 4.0, would change the life and way humans work and relate to one another (Radziwill, 2018). These technological changes are developing very fast so that every nation must continue to improve in facing these changes with life skills that are adaptive to this paradigm shift. These skills are called 21st-century life skills. If at this time we expect our students to be able to compete globally, then they must become reliable communicators, creators, collaborators, and critical thinkers (4C) (Erdogan, 2019).

Wagner (2008) and Harvard University's Change Leadership Group identified 7 types of competencies and life skills of the 21st-century that an individual needs to be able to compete and survive life, get a job, and fulfill their responsibilities as citizens

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who contribute to advancing their nation. As for 7 skills are described as follows: (1) critical thinking and problem-solving skills, (2) collaboration and leadership management skills, (3) flexibility and adaptability in various environments, (4) innovative and entrepreneurial, (5) able to communicate effectively both orally and in writing, (6) able to access and analyze information (digital literacy), and (7) have curiosity and creative imagination. This is also confirmed by Trilling & Fadel (2009), the Pacific Policy Research Centre (2010), and Boholano (2017) where the results of their studies show the importance of mastering 21st-century skills to be able to compete globally and achieve the transformation required for success.

However, based on the results of PISA (the Program for International Student Assessment) in 2015, Indonesian students' mathematical literacy skills were still low, Indonesian students ranked 63 and had an average score of 386 for mathematics, 62 and 403 for science, and 64 and 397 for literacy from 70 countries (Schleicher, 2016). Based on this survey, we can conclude that the ability of Indonesian students aged 15 years in mathematical literacy (including formulating, applying, and interpreting mathematical phenomena in various contexts) is still far below the average achievement of other participating countries. Stacey (2011) revealed that 76.7% of Indonesian students are at level 2 at the mathematics literacy level. The previously obtained scores indicate the phenomenon that on average students in Indonesia when studying are only accustomed to memorizing, remembering knowledge such as facts, scientific names, simple formulas, and terms as well as recognizing concepts and carrying out simple procedures but have not been able to carry out analysis, synthesis, and evaluation of a problem-solving in everyday life phenomena (Afriana et al., 2016 & Wijaya, 2016).

Education for the younger generation has a very important role, in accordance with the goals of national education, students are required to be able to develop knowledge, skills, attitudes, and values that enable students to contribute and sustainably benefit from the future. So, this is a very important goal to prepare the young generation with a good education system and adapt to technological developments. Educational institutions need to equip students with the skills they need to become active, responsible, and actively involved citizens (Schleicher, 2019). The development of the potential of students can be carried out during the learning process through the development of hard skills and soft skills following the four pillars proclaimed by UNESCO: learning to know, learning to do, learning to be, learning to live together (Yokhebed et al., 2016).

Science learning in the 2013 curriculum has provided a reference in selecting a learning model that is in accordance with the scientific approach. The learning model in question includes Project Based Learning (PjBL), Problem Based Learning (PBL), or Discovery Learning (Kemdikbud, 2014). The choice of learning model is left to the teacher by adjusting the characteristics of the teaching material. Project-based learning is a student-centered learning model and provides meaningful learning experiences for students. Student learning experiences and concept acquisition are built on the products produced in the project-based learning process.

Hertiandito (2016) reveals that one of the factors causing the low mathematical literacy skills of Indonesian students is that they are not used to and are trained to solve mathematical problems with TIMSS and PISA characteristics, where TIMSS and PISA questions are in the form of problem-solving problems that require literacy skills to solve. Furthermore, research on the integration of STEM in PjBL on scientific literacy is still rarely done, in Indonesia itself STEM research is still rare even though the trend is increasing from year to year (Afriana et al., 2016). The results of research by Tseng et al. (2013) revealed that PjBL integrated STEM can increase student interest in learning, make learning more meaningful, help students solve problems in real life, and support future careers. Besides, the mastery of teachers' understanding and skills in integrating STEM in learning is still lacking (Akaygun and Aslan-Tutak, 2016). So that, this literature review article can provide an overview of the STEM framework, principles, and strategies for implementing STEM in learning and provide prospects for increasing students' scientific literacy skills using STEM.

RESEARCH METHOD

The method used in writing this paper uses literature review. The literature review method is a series of activities related to the method of collecting library data, reading and taking notes, and managing research materials (Rahayu et al., 2019). A literature review can be an informative, critical, and useful synthesis of a particular topic (Bolderston, 2008). Data processing is done by combining some information that will be used as arguments and perspective problems. The technique of presenting the results of descriptive writing is carried out in an argumentative way to describe STEM principles, work series, implementation strategies, obstacles, and their prospects for improving students' scientific literacy skills in the future in Indonesia.

RESULTS AND DISCUSSION

STEM (Science, Technology, Engineering, and Mathematics)

Currently, one of the trends in education in preparing for the industrial revolution era 4.0 is the development of a multidisciplinary learning model known as STEM *(Science, Technology, Engineering, and Mathematics).* The abbreviation STEM is the brainchild of the NSF (National Science Foundation) in the United States which conducts in-depth research to find learning approaches that can integrate multidisciplinary fields of science effectively (Gonzalez and Kuenzi, 2012). STEM is learning which integrates the concepts of science, technology, engineering, and mathematics to develop creativity and day-to-day problem solving using a scientific approach commonly used by engineers and scientists (Winarni et al., 2016). STEM learning has been adopted by various countries such as Taiwan, where Taiwan has integrated STEM as part of its curriculum (Lou et al., 2011). Other countries that have implemented STEM include America, Malaysia, Finland, China, and the Philippines.

The STEM approach to learning can produce meaningful learning for students through the systematic integration of knowledge, concepts, and skills. (Afriana et al., 2016). STEM learning needs to emphasize several aspects in the learning process including (1) asking questions (*science*) and defining problems (*engineering*); (2) develop and use models; (3) planning and carrying out investigations; (4) analyzing and interpreting data (*mathematics*); (5) using mathematics; information technology and computers; and computational thinking; (6) building explanation (*science*) and designing solutions (*engineering);* (7) engage in arguments based on evidence; (8) obtaining, evaluating, and communicating information (National Research Council, 2014).

The application of STEM learning can be divided into 3 types, namely: 1) silo approach (separate) wherein this approach the material is taught separately between STEM subjects, 2) embedded or planted approach wherein this approach positions the main fields of science and fields of science others only as a support for studying this main field of science, and 3) an integrated approach wherein this approach connects various materials in the STEM field and is taught at the same time so that interest arises, critical thinking skills and problem-solving skills. an integrated approach is the best approach to teach STEM in the classroom (Alatas and Yakin 2021; Murnawianto et al., 2017).

Scientific Literacy

Literacy comes from the English word uptake *literacy* which means the ability to read and write. While the term science is taken from Latin, namely "*Scientia*" which means knowledge. Science can also be defined as a process of discovery that searches for facts, concepts, and principles of the universe to work systematically and procedurally. Specifically, scientific literacy can be defined as a person's ability to understand, formulate, apply, and interpret science in various contexts, including the ability to reason and use concepts, procedures, and facts to describe, explain, or predict phenomena or events (Schleicher, 2019).

The results of further analysis of PISA data for Indonesian children resulted in several findings including: 1) learner literacy outcomes were low, with an average of around 32% for all aspects, consisting of 29% for content, 34% for processes, and 32 % for context, 2) there is a relatively low inter-provincial diversity of the level of scientific literacy of Indonesian students, 3) the ability to solve problems for Indonesian children is very low, far from countries such as Malaysia, Thailand, or the Philippines.

More specifically, scientific literacy, one part of which is the focus is the ability to solve problems (Schleicher, 2014). This one ability can be developed by providing many non-routine problems that students rarely encounter in classroom learning. Of course, students need capital in solving problems, namely by understanding the material or adequate mathematical concepts (Wijaya, 2016). According to Ojose (2011), in mathematics literacy according to PISA, there are several important components, namely mathematics thinking and reasoning, mathematical argumentation, mathematical communication, modeling, problem posing and solving, representation, and symbols.

STEM Framework

Integrating STEM in learning requires an appropriate framework to serve as a reference (Kelley and Knowles, 2016). Building an integrated STEM learning framework is a fundamental perspective for solving complex real-world problems, using strategies that are unique to the four disciplines, while drawing links within and between those disciplines. The STEM framework has 4 main characteristics: 1) Problem-solving is an emphasis on the overall thinking process, 2) Understand complex real-world problems, global issues, and continuous problem development, 3) Focus on interdisciplinary relationships (i.e., horizontal connections), and 4) integration of STEM as four disciplinary domains (i.e., vertical learning) with the main problem. Because collaborative problem solving is an integral part of an integrated STEM curriculum, producing solutions to the problems at hand requires persistence, thoroughness, and scientific attitude, as well as student involvement in the problem-solving process. (National Research Council, 2014).

Problem-solving, like design thinking, was chosen as an overarching process to encapsulate STEM because problem-solving lies at the heart of all disciplines and can be said to be at the center of design thinking (design thinking proposes a more human-centric approach to problem-solving through design). (Tan et al., 2019) provided the idea of a STEM Quartet to show the relationship between discipline and its relationship to problem and problem-solving processes. The STEM Quartet framework visually is shown in Figure 1.

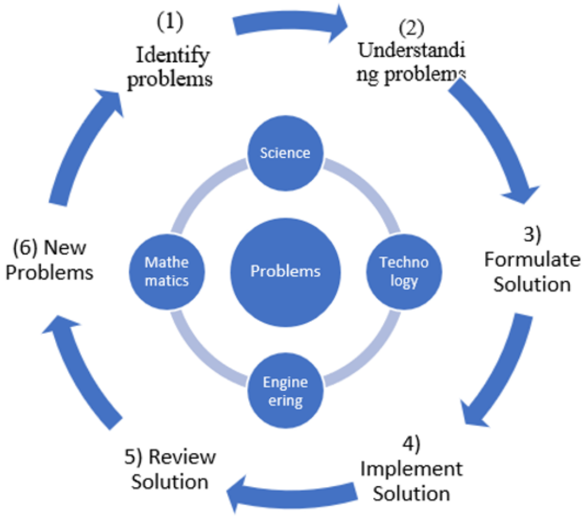

Figure 1. STEM Quartet Instructional Framework

In particular, the core phases of the problem-solving process in the STEM work design include: 1) identifying problems, 2) understanding problems, 3) formulating solutions, 4) implementing solutions, 5) evaluating/reviewing solutions, and 6) create/develop new problems. In the STEM Quartet, the authenticity of a problem is determined by its practical value and its relevance to the principles of Science, Mathematics, Technology, or Engineering in general. Guidance will be provided in the form of questions and information provided to students. Quartet problems emphasize persistence, curiosity, and problem expansion (Bereiter, 1992).

The success of the STEM framework must be determined by indicators and using appropriate instruments. The success of implementing a good STEM framework can be measured through the instrument named Integrated STEM Curriculum Planning and Rubric Reflection (Walker et al., 2018). The rubric covers eight categories include: 1) the context contained can be motivating and engaging, 2) integration of STEM content in an integrated manner, 3) student-centered instructional strategies, 4) emphasizes teamwork, 5) involves effective communication, 6) formative and summative assessment, 7) organizing learning objectives, and 8) integrating technology to improve the quality of learning.

The Integrated STEM Practices

The Next Generation Science (National Research Council, 2013) carefully uses language that describes the general practices of scientists and engineers. These practices become the results of learning science for students. Equally important to learning science concepts, scientific practice and skills are also emphasized as the main outcomes. Table 1 describes general science practices and engineering practices that provide an opportunity to compare similarities and differences (National Research Council, 2014).

Table 1. Practice and skills of STEM learning objectives

Sciences Practices	Technology Practices
1. Beginning with asking questions about phenomena or global issues that are urgent to find solutions. 2. Scientific investigation in the field or lab using scientific methods. 3. Analyze and interpret data diagrams, graphs, statistics from scientific observations using analytical tools. 4. Build a scientific theory to provide an explanation based on a phenomenon. 5. Build Arguments with rational evidence to explain natural phenomena, seek explanations, formulate evidence based on data, and test ideas with expert and peer understanding	1. Identify criteria, constraints, problem specifications. 2. Understand the material using brainstorming investigation for designing applications and running models, reading and learning from case studies, 3. Utilize technology in the preparation of work designs 4. Informed decision making, report and justify design decisions. 5. Describe the causes of failure and improve solutions, prioritize achievement criteria, optimize Communication of ideas, design decisions, justification, and design rules
Engineering Practices	**Mathematical Practices**
1. Begin with problems, needs, or wants that lead to engineered solutions. 2. Use models and simulations to analyze existing solutions. 3. Think carefully to make a mathematical model and have the skills to assess the performance of a design solution before making a prototype. 4. Designing solution designs using a systematic approach to solving engineering problems based on relevant scientific knowledge 5. Providing arguments with evidence for finding the best solution to a problem, the best solution is based on a systematic approach to comparing alternatives, formulating evidence from testing, and revising design solutions.	1. Understand the problem and have the curiosity to solve it. Students who are proficient in mathematics explain the meaning of a problem and have ideas for solving it. 2. Using abstract and quantitative reasoning abilities. Mathematically proficient students can decontextualize - make abstractions of a situation and represent them as symbols and mathematical expressions 3. Build viable arguments and critique other people's reasons. 4. Building a Model with Mathematics. 5. Using the right tools strategically 6. Find and take advantage of structures and look for and express regularity in repeated reasoning

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Implementation of The STEM Quartet Framework in Learning

For example, to illustrate how the STEM Quartet is implemented, the following steps are taken, first, set learning objectives, as for the example of learning taken is high school material for class X on geography science learning material about the solar system. The basic competencies in this learning are: 1) Analyzing the solar system, the rotation, and revolution of the earth and moon, and their impact on life on earth, 2) Presenting works on the impact of the rotation and revolution of the earth and moon on life on earth, based on observations or tracing various sources of information, assignments made by learning science as the point.

The second step is to formulate an authentic problem, based on the learning objectives to be achieved, we can use reference sources from books, magazines, newspapers, videos, or any source relevant to the learning objectives. Some of the questions that might be presented to students as follows: 1) make a model of the solar system of the Milky Way! 2) observe the rotational motion and what is the impact on the change of day and night? 3) calculate the ratio between the magnitude of the planets! and 4) estimate the trajectory distance of the planet using the concept of the circumference of a circle/ellipse.

Students examine each solution and identify limitations or problems with each solution. They explain limitations/problems in detail. Next, they formulate a solution by designing a prototype that will overcome the limitations (identified by students) of the existing solution. Teachers and students prepare references and resources needed in the project, the next step is to investigate the relationship between STEM fields of science so that the relationship between STEM fields and solutions for problem-solving will be used (the possibility of linkages between each field of science is different, there are very strong, strong, moderate, weak but all of them are in an integrated bond) and the final step is to develop a learning strategy that will be adopted by students, for example by group discussions, study tours, asking experts and others. Planning guide and evaluation tool for STEM tasks shown by the Figure 2.

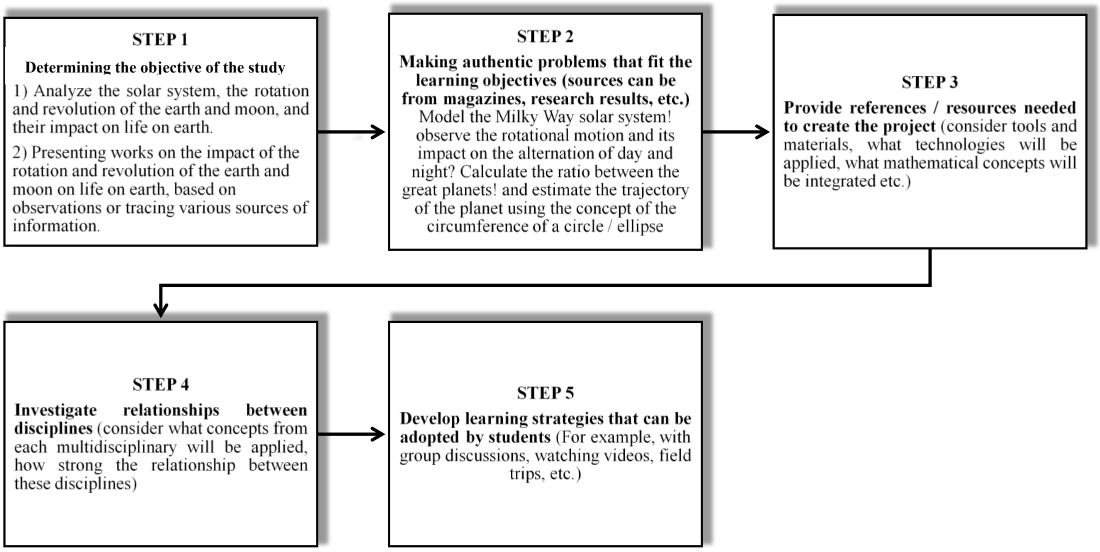

Figure 2. Planning guide and evaluation tool for STEM tasks.

The next step is the compilation of work steps that link the linkages between STEM fields in a single unit, Figure 3 illustrates the strength of the connections between different disciplines and the depth of vertical learning in one discipline. STEM Teachers are challenged to make explicit connections between science, engineering, and mathematics while simultaneously maintaining a motivating and engaging context for their students during their teaching (Dare et al., 2018).

The illustration explained authentic problems that will be integrated into solar system learning, then described the work steps that connect the STEM field and problem-solving strategies. In the problems posed above, we use science to find out the solar system, the concept of earth's rotation and revolution, to know the planets that orbit the sun, and to know the shape of the planet's trajectory. Furthermore, in the physics of astronomy, we use Kepler's Laws which are taught in high school physics material, as for the Kepler planetary movements are: Every planet moves in an elliptical path, the sun is in one of its focuses. The area swept at the same time is always the same. The quadratic period of a planet is proportional to the cube of its average distance from the Sun.

The field of technology helps students design miniature solar system projects using used materials or materials that are easy to find every day, students can also design illustrations of planetary rotation using the Adobe Flash animation application, Correl X7 design application can be used to design the planet's surface and draw the trajectories of the planets.

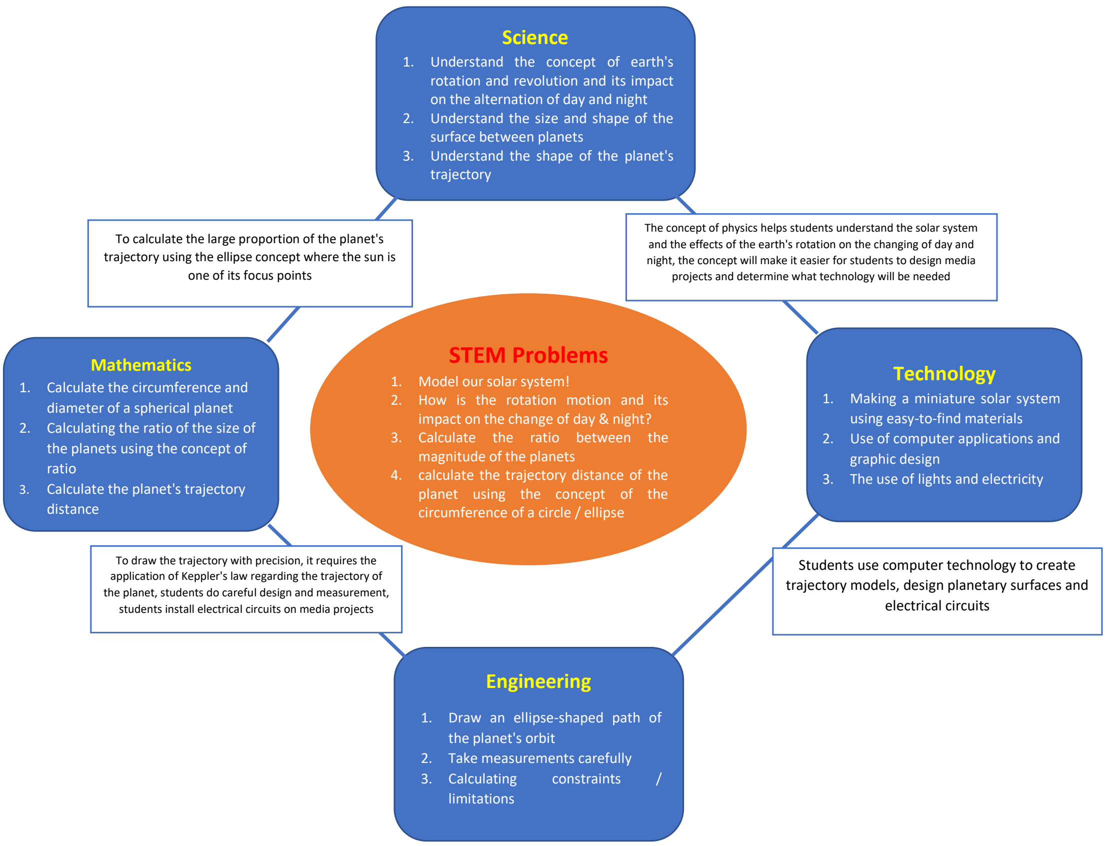

Figure 3. Planning linkages between STEM science fields

The Engineering field focuses on drawing elliptical planetary trajectories, taking careful measurements, simulating planetary rotations and revolutions as well as calculating constraints/limitations in project preparation. Finally, in mathematics, the students will compare the ratio of the size of each planet, then calculate the length of the path of each planet using the formula for the circumference of the ellipse and calculate the distance between the planet and the sun. All of these components support students' efforts to improve their scientific literature by starting to identify problems. All steps presented above can be a learning trajectory that can be perfected according to field observations.

In addition to the STEM theme regarding the solar system, there are several studies from Suwarma et al., (2015) regarding the integration of STEM in the material balloon-powered car as a STEM-based-learning media, Ismail et al. (2016) on the effectiveness of stem-based virtual labs in improving student scientific literacy, and Afriana et al., (2016) tried to improve skills scientific literacy by using the STEM approach in the aspects of knowledge: Air Pollution and the Greenhouse Effect. The three of them show positive results that STEM learning can improve students' science skills. This is in line with Moore et al., (2014) that stated the integration of STEM in learning will have an impact on 1) STEM learning can deepen students 'understanding of each discipline by applying the concept to a contextual problem, 2) expanding students' understanding of the STEM discipline through exposure to STEM contexts that are relevant to global, social and cultural issues and position students to be involved in finding solutions, and 3) provide an overview of the world of work and increase interest in STEM disciplines by increasing skills for students to enter the STEM field.

The Main Problems Faced in Implementing STEM

However, in the field of STEM application, there are still obstacles, however, based on studies from previous studies, it is found that the skills of teachers to integrate STEM into learning are one of the main focuses to be improved. The teacher is a very important component in implementing STEM in schools (Ogan-bekiroglu and Caner, 2018). One of the biggest problems faced is the lack of teacher skills in integrating science and mathematics effectively in the context of learning, in this case, the teacher must master the knowledge and pedagogical skills to integrate the science and technology of mathematics into a complete and comprehensive concept, which is ready to be applied in the classroom (Akaygun and Aslan-Tutak, 2016).

McDonald (2016) has conducted a study where the results of this study state that the role of teachers is very vital, effectively influencing student attitudes, motivation, and achievement. With professional skills, the teacher can improve student STEM literacy. How does the teacher conceptualize, interpret and then determine STEM content that affects the learning experience of students in the classroom (Zakharov et al., 2020). Wang et al., (2011) reveals the results of their research on a case study that discusses teacher perceptions of STEM integration in the classroom to look deeper into teachers' understanding of how to integrate STEM in learning. The results showed that further research and workshops were still needed for teachers to be skilled at integrating STEM in learning. When we understand how important the role of a teacher is in the implementation of STEM learning in the classroom, so we must support the teacher by providing not only an understanding of the content of disciplines but also the pedagogical skills needed to implement it in the classroom (Akaygun and Aslan-Tutak, 2016; Dare et al., 2018; Estapa and Tank, 2017).

CONCLUSION

Based on the results of the literature review, the authors suggest that the key to success in implementing STEM in the classroom is to prepare STEM educators with a conceptual understanding of the principles, frameworks, and strategies of integrated STEM implementation and teach key learning theories from the four STEM fields will be integrated, then increasing pedagogical skills and mastery of technology are needed to support learning. Also, the development of professional experience for teachers in implementing STEM in various cross-materials is very much needed to provide a strong conceptual framework of an integrated STEM approach and build their confidence in teaching an integrated STEM approach. Support from various parties including the government, educational institutions, and stakeholders are also needed to work together to popularize the STEM learning approach in schools with the hope that more and more students who learn using the approach will be able to improve students' scientific literacy skills and boost the results of TIMSS and PISA scores for Indonesian students.

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