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Integrated STEM Education in Indonesia: What Do Science Teachers Know and Implement?

Abas Hasyim Muchtar*, Lin Ding

Department of Teaching and Learning, College of Education and Human Ecology,
The Ohio State University, 1945 North High Street, Columbus, Ohio, USA.

*Email: muchtar.1@osu.edu

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Abstract. Integrated science, technology, engineering and mathematics (STEM) education has been a popular topic worldwide for the last few years. However, only a few studies have examined this topic in Indonesia. This literature review is to fill the gap by focusing on science teachers' perspectives on the STEM education approach at the secondary school level, including what they know and what they implement in science classrooms. For this purpose, 48 research articles published in national and international journals and judged to be pertinent to the current study, were reviewed. The results emerging from most of the existing research indicated that Indonesian science teachers in general were familiar with the integrated STEM teaching approach. However, more than half of them never tried implementing it in their classes. In addition, the studies revealed that project-based learning was the most frequently used method in STEM-based science classes. Teachers in science classes mainly employed integrated STEM education approach to promote 21st century skills such as creative and critical thinking, problem-solving, and literacy.
Keywords: STEM education, integrated STEM approach, science class, secondary education

Introduction

STEM education has been a popular global topic for the last few years. STEM itself is the acronym for science, technology, engineering, and mathematics (White, 2014). Since the first time it was introduced, STEM has been considered as a vital element of a country to be advanced in the global economy (White, 2014; Penprase, 2020). In teaching and learning context, one of the main discussions of this topic nowadays is focused on conversations around integrated STEM education. Here, STEM education generally refers to an integrated education pedagogy or an approach in teaching and learning that incorporates science, technology, engineering, and mathematics disciplines (Wahono et al., 2020). In other words, it is an interdisciplinary approach of at least two or more disciplines in which each of the subjects is not perceived and taught as a single independent subject isolated from other STEM subjects. This approach results in constructing knowledge, skills, and processes of those STEM subjects simultaneously and utilizing the connection between them to solve real-world problems (Penprase, 2020). Concepts and skills are not learned separately but are linked and learned from two or more disciplines as a way to deepen knowledge and prowess. For example, when students learn about climate change in science class, they are expected to be able to not only construct and employ their scientific understandings but also recognize, represent, and utilize expertise in mathematics, technology, and/or engineering to solve authentic problems related to the lesson topics.

One main objective of the integrated STEM education approach is to equip students with 21st century life skills such as critical thinking, creativity, communication, collaboration, problem-solving, and digital literacy that may lead them to be more marketable as future workforces (White, 2014; Wahono et al., 2020). Furthermore, the integrated approach helps prepare competitive graduates to fulfill the demands of the growing global economy (Wang et al., 2011; Parmin et al., 2020; Rahmaniar, 2020). Considering those significances, it is unsurprising that many countries, including Indonesia, have started to learn, disseminate, and implement this approach in their educational practices.

In Indonesia, integrated STEM education approach is introduced by the government, educational institutions, and academics through various socialization efforts, training programs, and academic publications. In cooperation with the Southeast Asian Ministers of Education Organization (SEAMEO) for quality improvement of teachers and education personnel (QITEP) in Science and the Australian Academy of Technology and Engineering (ATSE), the government has introduced the integrated STEM education framework by conducting workshops since 2013. This measure aims to initiate the implementation of the integrated STEM education approach in Indonesia, particularly in learning science (Ministry of Education and Culture of the Republic of Indonesia, 2018). Some research has also been conducted to foster the development of the integrated STEM education approach in Indonesia. A study by Dita et al. (2019) reported that research topics about STEM education in Indonesia were dominated by the topics of learning strategies, materials, and media. Only a few studies have examined the progress of integrated STEM education development in Indonesia (Nugroho et al., 2019). An assessment is required not only to reveal but also to ensure the sustainability of such a development (Wahono et al., 2020). Therefore, further studies on integrated STEM education development in Indonesia are necessary.

Many scholars agreed that there is still a lack of consensus on the standard definition of integrated STEM education (National Research Council, 2014; Thibaut et al., 2018; Cheng et al., 2022; Forde et al., 2023). Sanders (2009) defined STEM education as integrative approaches to teaching and learning that incorporate at least two or more STEM subjects and possibly combine those disciplines with other fields of study. This aligns with the definition given by Moore et al. (2014), who described integrated STEM education as an attempt to integrate the four disciplines of science, technology, engineering, and mathematics into a single class, unit, or lesson based on connections between these disciplines and real-world problems.

In 2014, the National Research Council (NRC) argued that it is challenging to develop a precise definition of integrated STEM education due to its multidimensional nature. However, in their study on STEM integration in K-12 education, the NRC (2014) presented four main features as a framework of an integrated STEM education: (1) goals (statements of goals to be achieved); (2) outcomes (outcomes for students and teachers); (3) nature and scope (types of STEM integration, disciplinary emphasis, duration, size, and complexity); and (4) implementation (instructional designs, educator supports, and adjustment to the learning environment).

To better implement classroom instruction, Bryan et al. (2015: 23-24) defined STEM education as "the teaching and learning of the content and practices of disciplinary knowledge, which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies". Further, they also proposed five key characteristics that can be used to identify integrated STEM teaching and learning. These characteristics include: (1) some of the main learning objectives are defined by the content and practices of one or more anchor disciplines in science and mathematics; (2) the practices of engineering and engineering design of technologies serve as the integrator that provides context for the content to be learned; (3) integrating the engineering design/practices with the science and mathematics content through design

justification; (4) emphasizing the development of 21st century skills; and (5) solving a real-world problem or task through teamwork and communication.

In developing the conceptual framework of integrated STEM education, Kelley et al. (2016) proposed a system bounded by community of practices that connects situated learning, engineering design, scientific inquiry, technological literacy, and mathematical thinking. While Thibaut et al. (2018) concluded that there are five main components of integrated STEM teaching and learning. These components include the integration of STEM content, problem-centered learning, inquiry-based learning, design-based learning, and cooperative learning. In comparison, Roehrig et al. (2021) suggested seven critical components of integrated STEM education. Those are (a) focus on real-world problems, (b) centrality of engineering, (c) context integration, (d) content integration, (e) STEM practices, (f) 21st century skills, and (g) informing students about STEM careers. Additionally, Forde et al. (2023: 5) conceptualized integrated STEM education in their study as "an approach that focuses on the interconnectedness between the content and skills of the STEM disciplines; science, technology, engineering, and mathematics". Considering the commonality across the definitions from previous studies and the purposes of this literature study, we operationally conceptualize integrated STEM education as an approach to teaching and learning that links and incorporates the content, concepts, knowledge, skills, and/or processes of two or more STEM disciplines (science, technology, engineering, and mathematics) in solving real-world problems.

This literature review is conducted as an attempt to provide the latest information about the progress of STEM education in Indonesia, with a focus on science teachers' perspectives on the integrated approach at the secondary school level, including what they know and what they implement in the classrooms, as reported in the related articles published in national and international journals. The teachers' knowledge investigated in this study is reflected in their familiarity with the integrated STEM education approach and their interpretation of it, while their chosen teaching and learning methods represent their implementation practices. Therefore, this study is expected to answer the following questions through a systematic literature review:

1. To what extent are Indonesian science teachers in secondary schools familiar with integrated STEM education approach?
2. What are the instructional methods frequently utilized by Indonesian science teachers at the secondary school level when implementing integrated STEM education approach?

Methods

This literature review started with a search for relevant references in research databases, including academic search complete, ERIC, APA PsycInfo, education research complete, and web of science. The keyword entries used for identifying pertinent articles from the databases were STEM education, integrated STEM, science teacher, Indonesia, science learning, science lesson, and science teaching. An initial search generated a total of 90 articles. Considering the small number of results, we expanded the search to Google Scholar, which further yielded 3470 articles. Haddaway et al. (2015) recommended focusing on the first 200 to 300 articles in searching for articles on Google scholar. Those articles were then examined based on the pertinence of their titles and abstracts to the goals of the study. This process resulted in 279 articles. Several criteria were then established in order to find research publications that could meet the objectives of this literature review. Those criteria were: first, the research had to be conducted in Indonesia; second, it had to focus on integrated STEM education within a framework of science teaching and learning; and third, the title had to be relevant to the aims of this literature study. The abstracts of those articles were also evaluated to see the relatedness between those articles and the scope of the literature review. A total of 170 articles were identified

as potential studies for review. Further evaluation was conducted by examining four main criteria. They were the aim of the study, participants, methods, and findings of the studies. After assessing the articles, 48 of them were retained to be reviewed. The whole selection process of the articles was summarized in Figure 1.

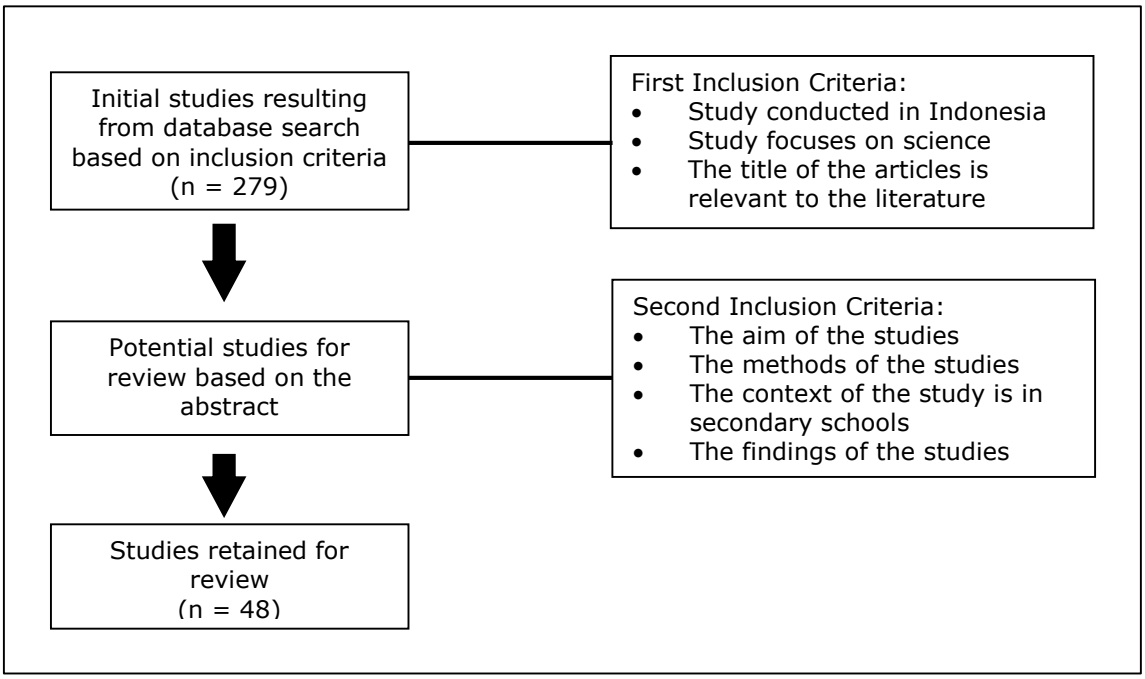

Figure 1. Diagram of the selection process

Results and Discussion

Science Teachers Familiarity with Integrated STEM Education

The first question of this study aimed to gain the latest information on Indonesian secondary school science teachers' familiarity with the integrated STEM education approach, particularly the level of their knowledge of the approach in teaching and learning. By evaluating the retained research articles used in this study, it is noticeable that there are still limited studies investigating the level of Indonesian science teachers' knowledge of the approach. Only 6 out of the 48 articles retained in this study measured the teachers' level of understanding of the integrated STEM education approach. Those articles were summarized in Table 1.

Table 1. Summary of articles for research question 1

Authors (Year)	Title	Instrument	Participant
Wahono et al. (2019)	Assessing teacher's attitude, knowledge, and application (AKA) on STEM: An effort to foster the sustainable development of STEM education	A survey in the form of a Likert scale	137 high school science teachers

Nugroho et al. (2019)	The movement of STEM education in Indonesia: Science teachers' perspectives	A set of open-ended and closed-ended questions	117 science teachers in secondary schools
Rahmaniar, A. (2020)	Perceptions of the Indonesian national curriculum in relation to integrated STEM education at the high school level	A survey in the form of a Likert scale	132 science teachers in secondary schools
Parmin et al. (2020)	Indonesian science teachers' views on attitude, knowledge, and application of STEM	A survey in the form of a Likert scale	93 science teachers in secondary schools
Permanasari et al. (2021)	STEM education in Indonesia: Science teachers' and students' perspectives.	A set of open-ended and closed-ended questions	100 science teachers in secondary schools
Sulaeman et al. (2022)	Teacher readiness in STEM education: Voices of Indonesian physics teachers	A set of open-ended questions	101 high school science teachers

One of the few existing studies that explored teachers' understandings of STEM education was conducted by Wahono and Chang in 2019. In their work, they investigated the progress of STEM education in Indonesia by measuring teacher perceptions of integrated STEM education through three assessment domains: knowledge, attitudes, and application. In their study, the researchers established and utilized a set of self-developed questionnaires covering the three domains for data collection. They found that even though the majority of Indonesian science teachers have a low level of knowledge about integrated STEM education, they have a positive attitude toward it and a moderate level of application of the approach. Their research showed that more than half of the teachers did not know about or had never heard of the term STEM. However, a different result was stated by Nugroho et al. (2019). In their investigation of the STEM movement in Indonesia, they concluded that the integrated approach is well understood by Indonesian science teachers. This conclusion was later supported by studies from Rahmaniar (2020), Parmin et al. (2020), Permanasari et al. (2021), and Sulaeman et al. (2022).

Rahmaniar (2020) carried out a study to examine the viewpoints of Indonesian educators regarding the infusion of STEM education into the national curriculum of the country. Her study revealed that most high school teachers who teach STEM subjects know what STEM is and have partially implemented some integrated STEM-based instructions in their classes. Likewise, Permanasari et al. (2021) found that most Indonesian science teachers (almost 80%) have a sound understanding of integrated STEM education approach, though only about 50% of the teachers implemented it in their classes. In 2020, adopting the instrument created by Wahono and Chang (2019), Parmin et al. conducted similar research that led to the opposite result as well that more than half of the science teachers (64.5%) claimed they had enough knowledge of integrated STEM education approach. Adding to the previous result, Sulaeman et al. (2022) found that Indonesian physics teachers were familiar with integrated STEM education approach and had basic knowledge of the approach; however, more than half of them never tried implementing integrated STEM teaching approach in classes.

There are some similarities we noticed from the studies mentioned above. First, almost all of those studies employed a set of questionnaires to explore the level of the teachers' familiarity with integrated STEM education approach. Unfortunately, the data gathered via this instrument seemingly did not provide the researcher with comprehensive

answers that could be used to recheck the validity of the responses. For example, in the studies of Wahono and Chang (2019) and Parmin et al. (2020), the questions were given in the form of a Likert scale survey that only required agree or disagree responses. Aligning with that, Nugroho et al. (2019) and Permanasari et al. (2021) employed a set of yes-or-no questions that did not allow respondents to offer more details for their answers. Hence, utilizing other types of data collection instruments, such as an in-depth interview, document analysis, or class observation, might help provide more comprehensive explanations and robust evidence for the researchers to make a convincing claim about the level and scope of Indonesian teachers' integrated STEM knowledge. Secondly, the selected articles informed us that most of the science teachers knew that integrated STEM teaching approach is about integrating one or more STEM disciplines, but how it will be carried out in their classroom practices is still not clearly revealed in those studies, which suggests a need for further investigations. Lastly, the participants involved in those studies are mostly from the western areas of the country, particularly Java and Sumatra islands. A study by Yuni (2017) showed that as an archipelago country and the fourth most populous country in the world, a gap in the quality of education across provinces in Indonesia, particularly between western regions and eastern regions, is a real issue in the country. This indicates the necessity of future studies that can recruit participants from more diverse areas of Indonesia.

The Implementation of Integrated STEM Education in Secondary Schools

The objective of the second question of this study was to explore the implementation of the integrated STEM education approach in Indonesian secondary schools. The investigation focuses on two primary contexts, the most popular teaching and learning instructional methods commonly employed in the classes and the learning outcomes mostly expected through the implementation of integrated STEM teaching approach. Based on the article evaluation process in this study, 42 articles were retained to be reviewed in order to answer the second research question. It is important to note that all of the existing articles used in this literature review mostly used the general term STEM education to refer to integrated STEM education approach. The selected articles were grouped into Table 2 and Figure 2 based on the claims made by the authors about the teaching and learning methods used in their respective studies.

In addition, the learning outcomes of each study were also summarized in Table 2 to give information about the learning outcomes that are mostly expected to be possessed by students after being taught with the integrated STEM education approach.

Table 2. Summary of articles for research question 2

Authors	Year	Teaching Method	Expected learning outcomes
Afriana et al.	2016	Project-based learning	Scientific literacy
Agustin et al.	2020	Problem-based learning	Cognitive test result/ conceptual understanding
Alfarisi, S.	2020	Project-based learning	Creative thinking skills
Alifa et al.	2018	Project-based learning	Creative thinking skills
Allanta et al.	2021	Project-based learning	Critical thinking skills Self-efficacy
Amatullah et al.	2019	Inquiry-based learning	Conceptual understanding
Ashari et al.	2021	Project-based learning	High-order thinking skills
Bukifan et al.	2021	Inquiry-based learning	Conceptual understanding
Devi et al.	2020	Project-based learning	Mathematical creativity
Dewi et al.	2020	Problem-based learning	Creative thinking skills

Fachrunnisa et al.	2021	Project-based learning	Problem-solving skills
			Creative thinking skills
Fitriansyah et al.	2021	Inquiry-based learning	Scientific attitudes
			Scientific work
Hanif et al.	2019	Project-based learning	Creative thinking skills
Haryadi et al.	2021	Blended learning	High-order thinking skills
Hasanah, U.	2020	Inquiry-based learning	Reasoning skills
Hudha et al.	2019	Inquiry-based learning	Scientific literacy
			Conceptual understanding
Islamyah et al.	2018	Inquiry-based learning	Critical thinking
Kanza et al.	2020	Project-based learning	Students' activeness
Kartini et al.	2021	Project-based learning	Problem-solving skills
Laila et al.	2021	Virtual laboratory	Problem-solving skills
Lestari et al.	2021	Project-based learning	Critical thinking skills
Mahjatia et al.	2021	Inquiry-based learning	Scientific skills
Maulana	2020	Project-based learning	Independence in learning
Maulidia et al.	2020	Problem-based learning	Creative thinking skills
Ningkaula et al.	2021	Discovery learning	Conceptual understanding
Nisa et al.	2021	Inquiry-based learning	Analyzing ability
Nuriyah et al.	2021	Blended learning	Conceptual understanding
			Creative thinking skills
Nurya et al.	2021	Children learning in science	Scientific thinking
Pahrudin et al.	2021	Inquiry-based learning	Critical thinking skills
Parno et al.	2020	Problem-based learning	Scientific literacy
Parno et al.	2021	Experiential learning	Problem-solving skills
Qadafi et al.	2022	Project-based learning	Creative thinking skills
Rahayu et al.	2021	Project-based learning	Conceptual understanding
Rahmawati et al.	2021	Project-based learning	Critical thinking
Ridha et al.	2022	Project-based learning	Creative thinking skills
Santoso et al.	2021	Inquiry-based learning	Critical thinking skills
Sasmita et al.	2020	Project-based learning	Conceptual understanding
Septiani et al.	2020	Problem-based learning	Learning interests
Syukri et al.	2020	Problem-based learning	Learning interests
Tahnia et al.	2022	Experiential learning	Scientific thinking
Wahono et al.	2020	Problem-based learning	Problem solving skills
Wijayanto et al.	2020	Project-based learning	Cognitive test result/ conceptual understanding

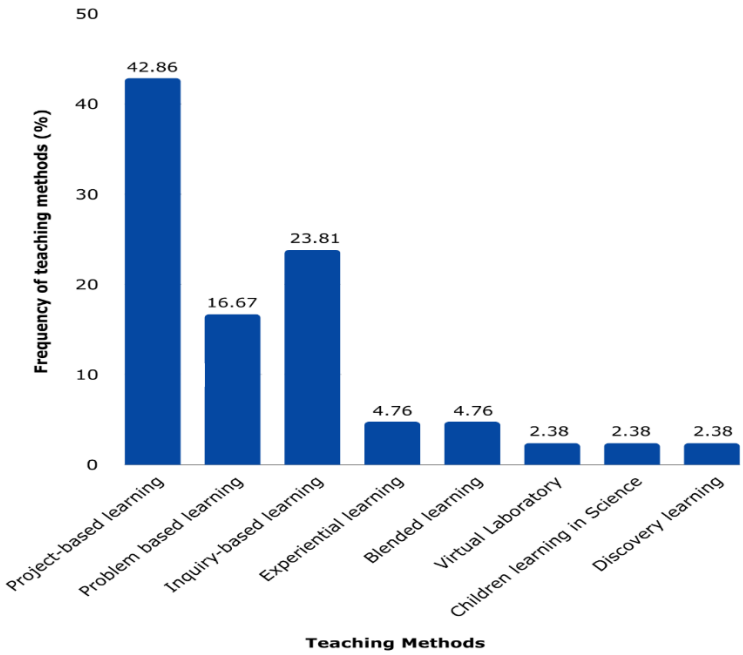

Figure 2. Frequency of used teaching methods

Figure 2 illustrates the common teaching and learning methods employed in Indonesian secondary education classes when the integrated STEM education approach is implemented. It is noticeable that project-based learning (PjBL) is the most frequently used method in science classes, while inquiry-based and problem-based learning (PBL) follow as the second and third highest chosen methods, respectively. On the other hand, other methods such as the virtual laboratory, discovery learning, and children learning in science are the least chosen ones to embed in the integrated STEM education approach.

More than 40% of the retained articles discussed the use of PjBL to improve and increase students' learning outcomes. STEM project-based learning leads students to a meaningful learning experience that can train them to solve real-world problems through a project by integrating knowledge, concepts, and skills from some STEM field disciplines, namely science, technology, engineering, and mathematics (Sasmita & Hartoyo, 2020; Wijayanto et al., 2020). In addition, the STEM-PjBL method emphasizes contextual learning that allows students to visualize their conceptual understanding through project-making activities (Kanza et al., 2020; Sasmita & Hartoyo, 2020; Rahmawati et al., 2021). Concerning the content and context, Afriana et al. (2016) and Ridha et al. (2022) concluded that PjBL is more aligned with the integrated STEM education frameworks.

In today's competitive and dynamic job market, employers are looking for individuals who not only possess academic knowledge but also demonstrate proficiency in essential 21st century skills. Critical thinking, creativity, communication, and collaboration are some fundamental abilities required in the contemporary world (Larson and Miller, 2011). These skills foster innovation, allowing individuals to contribute creatively and meaningfully to their workplace and/or communities. Given its significance, the implementation of an integrated STEM approach is expected to facilitate the development of these skills in students. The integrated STEM education approach, in general, promotes 21st century skills. This notion was mostly supported by the existing literature. The integrated STEM teaching approach increased students' creativity (Alifa et al., 2018; Devi et al., 2020; Dewi et al., 2020; Fachrunnisa et al., 2021; Hanif et al., 2019; Maulidia et al., 2020; Qadafi et al., 2022; Ridha et al., 2022). Students' critical thinking skills were also positively affected by the integrated STEM education approach (Islamyah et al., 2018; Atlanta &

Puspita, 2021; Lestari & Muhajir, 2021; Pahrudin et al., 2021; Rahmawati et al., 2021). Studies by Kartini et al. (2021), Laila & Anggaryani (2021), Parno et al. (2021), and Wahono et al. (2020) proved that the implementation of the integrated STEM education in the science classroom improved students' problem solving skills. While the studies of Afriana et al. (2016), Hudha et al. (2019), and Parno et al. (2020) emphasized the significance of the integrated STEM education approach in improving students' scientific literacy skills.

The selected research articles informed us that the integrated STEM education approach is mostly implemented within science classes at the Indonesian secondary education level by using methods such as PjBL, PBL, and inquiry-based learning, which aim to promote 21st century life skills such as creativity, critical thinking, problem-solving, and literacy. This finding confirms the presence of 21st century life skills as one of the main characteristics of integrated STEM education approach, as proposed by Bryan et al. (2015) and Roehrig et al. (2021). STEM education is expected to equip students with 21st century life skills such as critical thinking, creativity, communication, collaboration, problem-solving, and literacy (White, 2014; Wahono et al., 2020). Unfortunately, no empirical study has yet specifically explored or measured the effectiveness of the integrated STEM education approach in affecting students' communication and collaboration skills.

Furthermore, we noted that even though the previous research already utilized various methods such as observation, questionnaire, interview, and test to collect their data, only a few of the literature clearly provided a solid theoretical background that defined the learning outcome they intended to measure. A study from Hasanah (2020) that measured students' reasoning skills was one of the few studies that explained the importance of the skill under investigation and clearly defined what it was and what indicators were used to measure it. Additionally, although all of the selected studies claimed that the science lessons in their classes were conducted under the framework of the integrated STEM education approach, there was only a limited amount of information and explanation in most of the study articles to support the claim. Most of the studies did not provide either a clear theoretical framework to navigate the implementation of integrated STEM education or detailed descriptions of how it was carried out by the teachers in their classrooms. Without those pieces of information, it would be difficult to see the main differences between a so-called just science class and an integrated STEM-based science class. This finding indicates the necessity of more future studies on integrated STEM education in Indonesia. By addressing the limitations mentioned above, we hope future studies can help establish a standardized conceptual framework or a comprehensive model to guide teachers' effective implementation of this instructional approach in their classrooms.

Conclusion

This literature review focuses on two main purposes. The first is to explore Indonesian secondary science teachers' knowledge about integrated STEM education. More specifically, the study is aimed at examining Indonesian teachers' familiarity with and their interpretation of the integrated STEM education approach. Most of the existing articles stated that most science teachers knew about and were familiar with the integrated STEM education approach. However, over half of them never tried to implement it in their own classes. The second purpose of this study is to identify the most frequently used teaching methods that pair with the integrated STEM education approach in secondary science classes in Indonesia. The existing literature revealed that project-based learning was the most frequently used method in science classes at the secondary education level in Indonesia. Furthermore, teachers in science classes mainly employed the integrated STEM education approach to promote 21st century skills such as creativity, critical thinking, problem-solving, and literacy.

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