MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(5), em2262
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/13155

Pre-service teacher in STEM education: An integrative review and mapping of the Indonesian research literature

Muhamad Gina Nugraha [1,2*], Gillian Kidman [1], Hazel Tan [1]

[1] Faculty of Education, Monash University, Clayton, Victoria, AUSTRALIA
[2] Physics Education Department, Universitas Pendidikan Indonesia, Jawa Barat, INDONESIA

Received 06 February 2023 ▪ Accepted 27 March 2023

Abstract
STEM education has become increasingly popular, including for pre-service teachers (PSTs). Preparing PSTs in STEM-based practices is essential to generate STEM-ready teachers. This study reviews STEM education literature for PSTs and provides recommendations for future research and practices. We investigate the Indonesian context–the fourth largest populated country in the world and the largest economy in Southeast Asia. The bibliometric analysis of 31 research papers revealed that STEM education for Indonesian PSTs was first reported in 2017, rapidly increasing to involve 110 researchers. 15 disciplinary backgrounds from 31 higher education institutions across Indonesia have participated in STEM education research, indicating a collaboration, and inclusive implementation of STEM education. However, the integrative review revealed diverse perceptions of STEM implementation. We recommend a framework (STEM-DiMRECS) as guidance to conduct integrated STEM learning: **D**iscipline **I**ntegration, **M**ultiple representations, **R**ealistic and relevant problems, employing the **E**ngineering design process, **C**ollaboration, and **S**tudent-centered learning.

Keywords: STEM education, pre-service teachers, Indonesia, STEM framework, STEM-DiMRECS

INTRODUCTION

In Indonesia–the largest economy in Southeast Asia and the fourth most populous nation in the world, with more than 300 ethnic groups living in a diverse archipelago (Worldbank, 2022)–STEM (science, technology, engineering, and mathematics) education aims to improve the competency of its Indonesians. The Indonesian Ministry of Education and Culture (MoEC) has conducted various programs and partnerships. In 2018, the signing of a partnership agreement with Casio Computer CO., Ltd. (a Japanese-based electronics company) "marks our joint efforts to strengthen cooperation in the field of education, particularly in developing competencies in the fields of science, technology, engineering and mathematics" (MoEC, 2018). In 2020 the Ministry of Education and Culture conducted "KIHAJAR (KIta HArus belaJAR–we must learn) STEM" –an effort to actualize the Indonesian education vision (MoEC, 2020b). In 2021, through the SEAQIS program, *STEM learning* became one of the flagship programs of SEAMEO-QITEP (Southeast Asian Ministers of Education Organization-Quality Improvement for Teacher and Education Personnel) in Indonesia (MoEC, 2021). However, despite these milestones, STEM learning appears outside the Indonesian Education curriculum, which has led to different perceptions among the academic community about how STEM should be implemented and developed. This paper aims to explore the literature concerning the characteristics of Indonesian pre-service teachers' (PSTs') STEM education.

STEM Education Movement

STEM education movement has become global since its introduction in the 1990s (Bybee, 2010). The acronym STEM continues to expand and grow as a label involving at least one STEM discipline in the classroom or curriculum (Bybee, 2013). Ozkaya (2019) reported the STEM research trend from 1992 to 2017, finding STEM education research increasing, particularly in the last five years of this period. The United States dominates this research, followed by England and Australia, collectively endorsing STEM programs and courses and

✉ muhamad.nugraha@monash.edu **(*Correspondence)** ✉ gillian.kidman@monash.edu ✉ hazel.tan@monash.edu

Contribution to the literature

- A review of the movement, intervention, development, and conceptualization of STEM education for PSTs in Indonesia.
- A conceptual STEM framework resulting from the literature review as a guideline in implementing and developing integrated STEM learning.
- Recommendation in implementing and developing STEM learning for PSTs.

establishing STEM education movement. Key projects are, as follows:

1. United States: Project lead the way (PLTW), engineering by design program and the next generation science standard (NGSS) program (Ritz & Fan, 2015).
2. England: STEM national center, science community representing education (SCORE), STEMworks and the STEMNET (STEM network) (Ritz & Fan, 2015).
3. Australia: 10-year (2016-2026) national STEM school program to ensure all Australian youth achieve the essential STEM knowledge and skills (Council, 2015) .

The STEM definition varies. Hasanah (2020) reports that STEM has four different fundamental definitions: STEM as discipline, instruction, field, and career. In the educational context, the STEM acronym is used "for anything and everything vaguely related to one or combination of the four disciplines" (p. ix) (Vasquez et al., 2013). The STEM abbreviation itself has extended to other disciplines and focuses, such as STEAM, with the "A" for Arts; STREAM, with the "R" for Reading and wRiting; STEMM, with an additional "M" for Medicine; and steM with the only capitalized "M" to show Mathematics as the focus (Tan & Kidman, 2021). This broad and different interpretation could lead to confusion for policymakers, curriculum developers, school communities, and higher education to adopt, develop and implement STEM education in their institutions. To prevent further different perceptions, in this study, the term STEM refers to educational context as a learning approach to learn science, technology, engineering, and mathematics in an integrated manner by removing the traditional barriers between the disciplines (Jolly, 2017; Vasquez et al., 2013), with implementation including STEM teaching and learning, development, and assessment.

Regarding STEM implementation, there are different terms and definitions for STEM integration; however, researchers agree that the greater the integration, the better the learning outcomes. There is little agreement on what constitutes integration. Roberts and Cantu (2012) introduce three approaches for teaching STEM, including the STEM disciplines being taught separately (silo approach), one or more disciplines embedded in another STEM discipline (embedded approach), and the STEM disciplines/content areas taught as one subject (integrated approach). Vasquez et al. (2013) propose four levels of integration: disciplinary, where STEM disciplines are learned separately; Multidisciplinary, in which each discipline's principles and skills are learned individually by the pupils while yet referencing a common topic; Interdisciplinary learning involves concepts and skills from two or more closely related disciplines to deepen knowledge and abilities, and; Transdisciplinary learning consists of applying knowledge and skills from two or more disciplines to real-world issues or projects to shape the student's learning experience. Also, Hobbs et al. (2018) promote three integration models: the holistic model representing all disciplinary and interdisciplinary activities, the interconnected model representing interdisciplinary activities, and the amalgamated model representing a meta-discipline that focuses exclusively on the areas of overlap and convergence among STEM disciplines.

Teacher and Pre-Service Teacher on STEM Education

Research has shown that STEM learning is advantageous to students, e.g. a positive impact on learning outcomes (Amalya et al., 2021; Yildirim, 2016), cultivating learning attitude, technical thinking, and creativity (Chen & Chen, 2021; Oschepkov et al., 2022) and contribute to developing 21st-century skills (Celiker, 2020; Sheffield et al., 2017). Undeniably, the teacher who facilitates the learning experience for students drives success in STEM learning. Teachers with good STEM understanding (Keane & Keane, 2016), positive beliefs and sufficient competencies (Park et al., 2016) will create a favorable STEM learning environment in the classroom. The teacher, as the fundamental learning source (Saat et al., 2021), is essential in facilitating the learning process. The teacher creates a problem to challenge students' higher-ordered thinking and encourages students to actively participate in the learning process (Suebsing & Nuangchalerm, 2021). In contrast, deficient STEM teachers' knowledge and understanding will lead to limited and ineffective learning (Bell et al., 2018). Hence, preparing teachers to be STEM-ready is essential.

To enhance teacher competence, both in-service and PSTs require professional development (PD) activities. In Southeast Asian region, Saat et al. (2021) conducted PD in Malaysia through a scientist-teacher-students partnership (STSP) program. The program increased teachers' cross-cutting STEM knowledge, elevated confidence and enthusiasm, and provided exchange information and support between schools and universities. In Indonesia, Toto et al. (2021) reported increased teachers' understanding and readiness to implement STEM education after joining a science learning simulation PD workshop. Similarly, through a Thai-based PD program, Suebsing and Nuangchalerm (2021) reported increased teacher understanding and satisfaction toward STEM. However, research indicates most teachers lack the knowledge and preparation to implement STEM education, leading to dissatisfied teaching STEM experiences and resistance (Jho et al., 2016). PD programs are usually limited, selective and restricted to teachers from a particular discipline background or pre-requisite IT and technological skills. Thus, in addition to PD for in-service teachers, a more systematic and continuous STEM preparation program is needed. STEM education for PSTs could address this problem, creating a future workforce of classroom teachers with the skills, knowledge and experience regarding STEM education (Vasquez et al., 2013). In addition, Kim et al. (2019) and Radloff and Guzey (2016) showed that insufficient PST knowledge in the multiple-discipline STEM content would be detrimental to STEM learning in the future. Promoting STEM education for PST includes the STEM learning process and development. Ayaz and Sarikaya (2019) conducted engineering design-based science teaching to enhance PST perception toward STEM. Bartels et al. (2019) reported collaborative mathematics and science methods to improve STEM understanding and ability to design lesson plans. In STEM development, Noh and Khairani (2020) developed an assessment to measure attitudes of PST toward STEM, and Ngabekti et al. (2019) constructed a STEM-based mobile learning media in the ecosystem context for biology and science PST.

STEM Education for Pre-Service Teachers in Indonesia

In Indonesia, STEM education is increasing, both in research and practice, for all levels of education. In Southeast Asia, based on a bibliometric review of STEM education (Thao et al., 2020), between 2000-2019, Indonesia was the third highest nation contributing to STEM education research, behind Malaysia and Thailand researchers. In that report, Thao et al. (2020) showed that the trend of STEM education research from Indonesia continuously increased, with the highest jump occurring from 2018 to 2019. Similarly, Farwati et al. (2021) reported a massive increase in STEM education implementation in Indonesia through a scoping review in 2015-2020, with the highest growth in 2019 and a slight decrease in 2020 due to being affected by COVID-19 pandemic disruptions. Farwati et al. (2021) also showed that STEM education had been implemented on all levels of education, from elementary to undergraduate, with high school as the most significant portion. In addition, they also reveal a wide range of Indonesian provinces that implemented STEM education, with West Java, East Java, and Central Java as the three dominant provinces conducting more than 60% of the research. Farwati et al.'s (2021) and Thao et al.'s (2020) reports show that Indonesian researchers are conducting STEM education research, yet little STEM education research involving PST is reported.

Several Indonesian universities have established STEM centers (e.g., Indonesia University of Education [http://stemedcenter.upi.edu] and State University of Semarang [https://mipa.unnes.ac.id/v3/tag/stem]). As STEM education has a diffuse definition and broad interpretation, the research and implementation of STEM education for PSTs must be stronger. A comprehensive literature review is needed to provide direction for future STEM implementation and development in Indonesia.

Literature reviews regarding STEM education in the Indonesian context are beginning to emerge. Nugroho et al. (2021) conducted a literature review, "the urgency of STEM education in Indonesia", to investigate how to implement STEM education for teachers. Meanwhile, Nurwahyunani (2021) reviewed the literature on improving the quality of science learning in Indonesian schools through the STEM approach. Zulaikha et al. (2021) conducted a literature review concerning the STEM approach in physics learning. Thus, our work addresses this knowledge gap by the consideration of the following two research questions:

Q1. What is the movement of STEM education research for PSTs in Indonesia?

Q2. How is PST STEM education implemented in Indonesia?

This study contributes to the knowledge corpus by exploring Indonesian PST STEM education. Since Indonesia is a vast country with a diverse cultural community (the fourth most populous nation in the world with more than 300 ethnic groups), our review findings are presented as recommendations for an international readership.

METHODS

Research Design

We employed the bibliometric method (Zupic & Čater, 2014) to map STEM education research on Indonesian PSTs. We also undertook an integrative review (Toronto & Remington, 2020) to provide insight into the field. The bibliometric approach maps a field's structure, development and "topographical" trends (Hallinger & Kovačević, 2019; Sharma, 2019). The integrative review provides an understanding and insight (Toronto & Remington, 2020), leading to new framework and perspectives (Torraco, 2005) through integration, critique and synthesis of representative literature. Recently Tan and Kidman (2021) undertook an integrative review of STEM authentic assessment, and Ng et al. (2022) proposed a conceptual framework for STEAM integration. The Bibliometric method mapped research on STEM modules (Triwahyuningtyas et al., 2021) and STEM education in the ASEAN region (Thao et al., 2020). Hernández-Torrano and Courtney (2021) employed both methods to map the research on large-scale international assessments to provide trends, development and structure. We adopt these methods to obtain a comprehensive view of STEM education for Indonesian PSTs for future research and practices.

Data Sources

A systematic search collected research articles from international and local databases (See **Appendix**). ProQuest Education and 14 STEM journals that mentioned science, mathematics and technology in their title (Tan & Kidman, 2021) also became document sources. The search was conducted in May (ProQuest Education) and June 2022 (14 STEM journals) with the keyword "STEM preservice teacher" and "STEM pre-service teacher", without any filter, including year limit. The Indonesian context and search filter were not used in the search process as we were concerned the "Indonesian" word did not exist in the title and abstract of the articles. A total of 1,872 articles were found, consisting of 1,485 ProQuest Education articles and 387 papers from 14 STEM journals. Double duplicate checking, title and abstract screening, and full-text reading were conducted to filter and select the relevant literature. This inclusion and exclusion process follows the preferred reporting items for systematics reviews and meta-analysis (PRISMA) guidelines described by Moher et al. (2009), as shown in **Figure 1**. Hence, 14

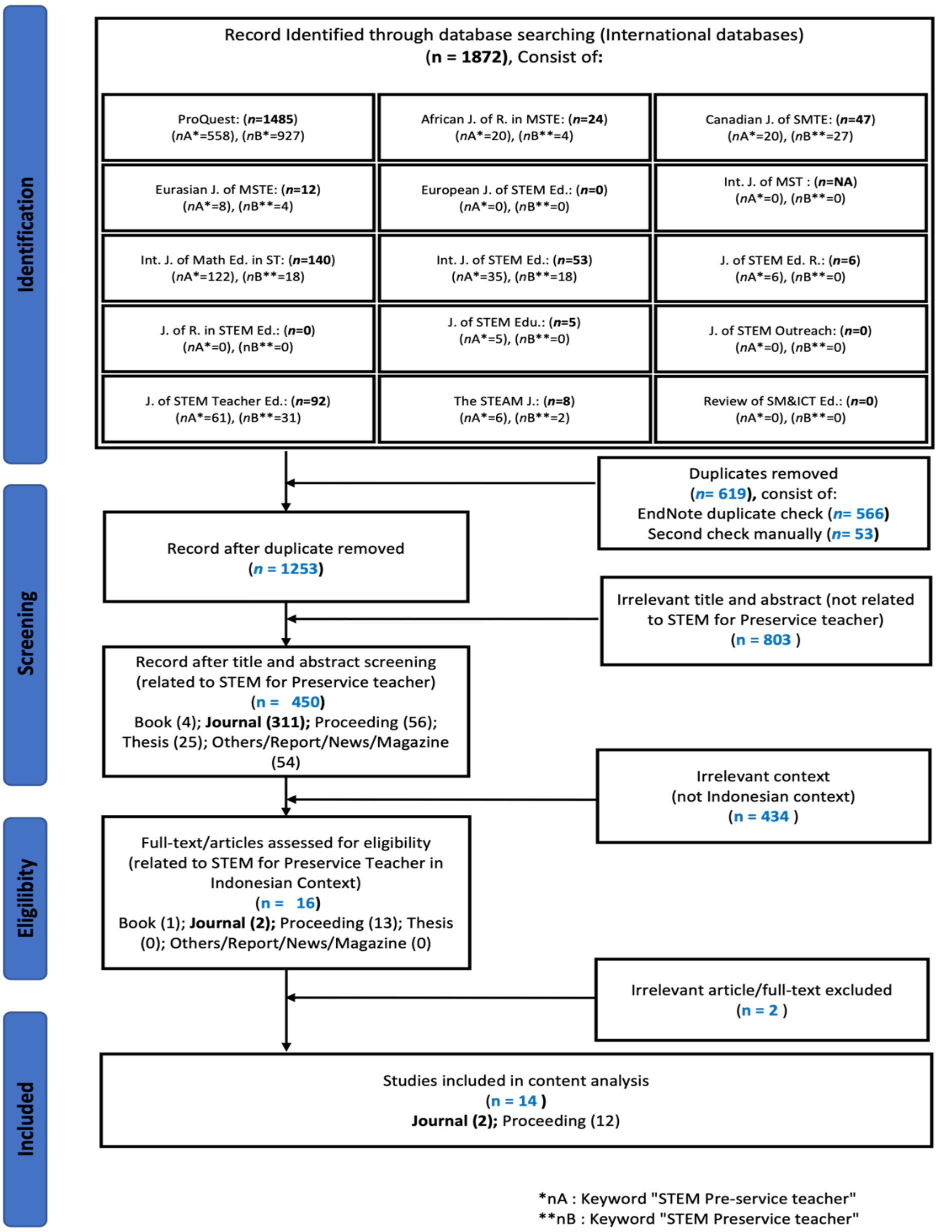

Figure 1. Flow diagram for the search and selection of literature process from international databases (Source: Authors' own elaboration)

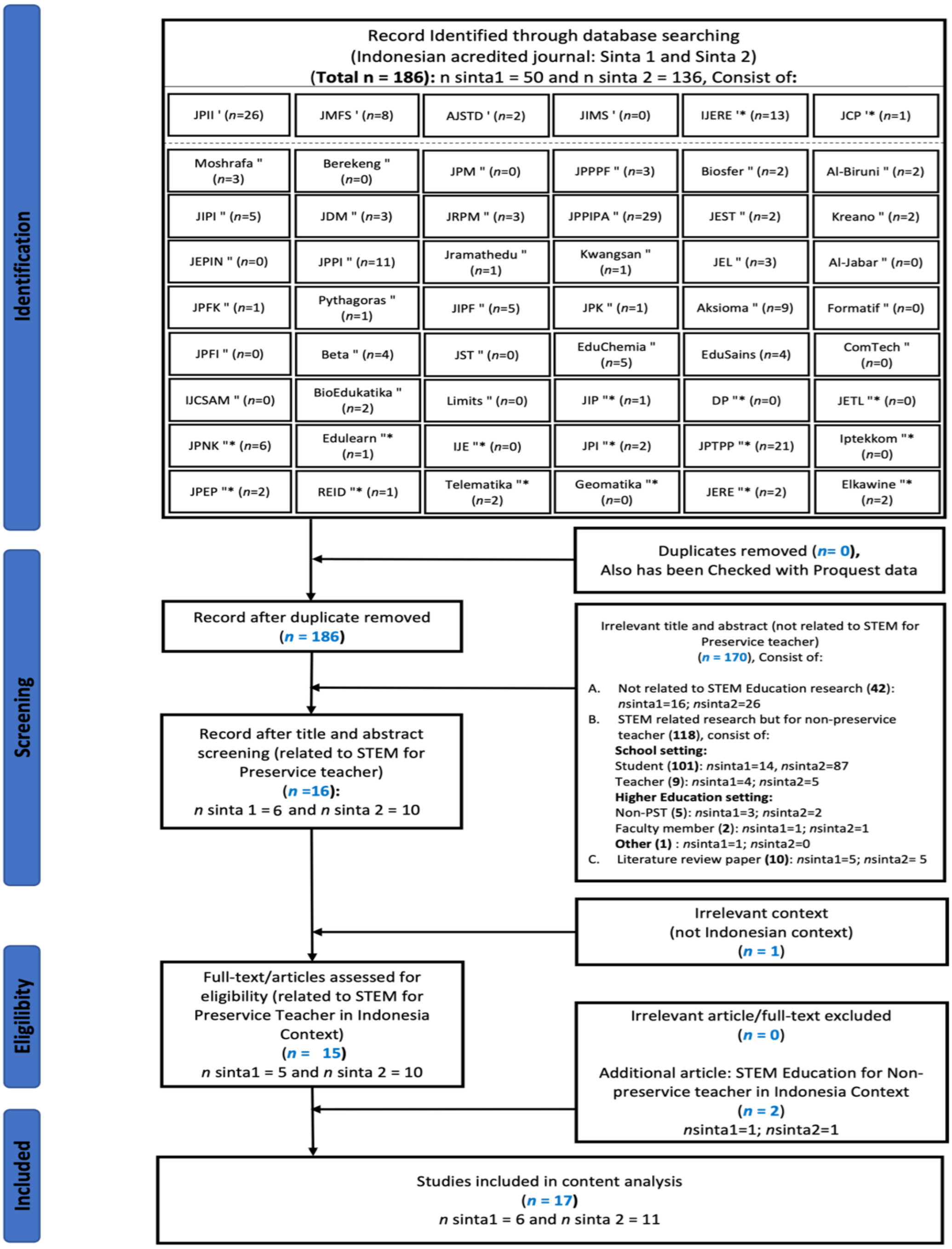

Figure 2. Flow diagram for the search and selection of literature process from local databases result (Source: Authors' own elaboration)

articles from international databases were included for content analysis.

Local databases were used to gain more Indonesian-context research. Indonesian MoEC has provided a website portal (https://sinta.kemdikbud.go.id) called Sinta (science and technology index) to access accredited Indonesian journals. Our study used Sinta 1 (indexed by Scopus) and Sinta 2 (the first- and second-best ranking) as the journal source. The search was conducted in August 2022 by selecting a STEM-related journal, applying an education-only filter, using the keywords "STEM", "Science", "Mathematics", "Physics", "Chemistry", "Biology", "Engineering", and "Technology" and their translation in the Bahasa Indonesia language. In addition, the general education journal with "education" words without mention of any specific discipline in their name was added. Second, the keyword "STEM" was used for each selected journal to obtain relevant articles. 17 Sinta 1 and Sinta 2 journals were selected through these two steps, illustrated in **Figure 2**. A combined total of 31 papers were accepted.

Data Analysis

We summarized frequent issues and themes, then coded and extracted these into a categorization matrix using NVivo and Microsoft Excel software. We also

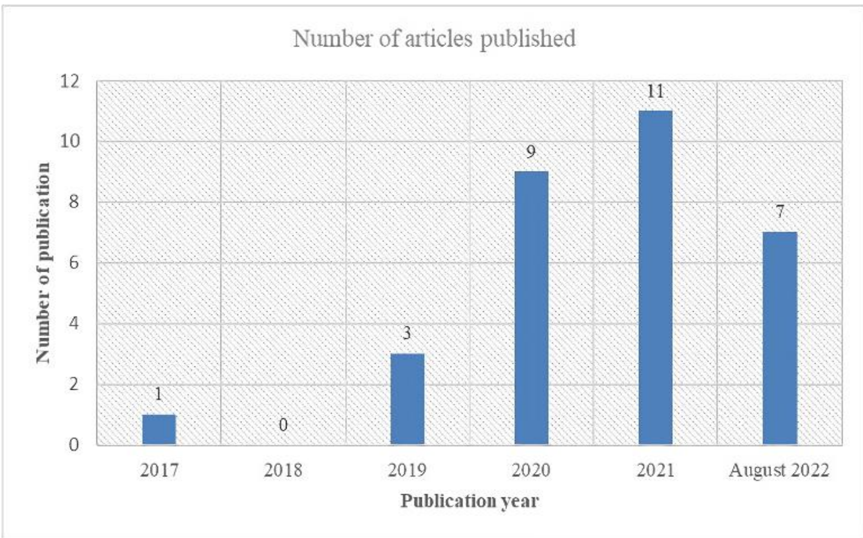

Figure 3. Annual publication of STEM education research for Indonesian pre-service teachers (Source: Authors' own elaboration)

employed Google maps to provide the research location across Indonesia and VOSviewer software (Van Eck & Waltman, 2010) to visualize the network and relationship among the authors and the research keyword tendency in our corpus.

RESULTS

In this section, we delivered an analysis, synthesis, and visualization of the selected documents to address each research question.

What is the Movement of STEM Education Research for Pre-Service Teachers in Indonesia?

Our corpus indicates a positive and promising movement on STEM education for PSTs in Indonesia. The first publication was reported in 2017, which has risen notably since 2020. In our 31 selected articles, 110 researchers were involved, with 30 studies conducted collaboratively. The research participants come from various disciplines–childhood PST, elementary school PST and specific disciplines PST (biology, physics, chemistry, mathematics, science, computer science, educational technology, electronics engineering, and informatics and computer engineering). Participants were also STEM disciplinary experts and lecturers. At least 31 universities in 15 provinces of Indonesia have conducted STEM education for PSTs. We note three STEM research focus areas are favored in Indonesian PST research: STEM intervention, conceptualization, and development.

Below we elaborate on the movement and development of STEM education for PST in Indonesia regarding the research trajectory, researcher involvement, participants' background, distribution of research locations across Indonesia, and research focus.

Research trajectory

The number of annual publications, the distribution of publishers and the research topics illustrate the research trajectory in this study. The first STEM education publication on Indonesian PST was in 2017 by Winarno et al. (2017). It investigated STEM career interests of science PST examining linearity between their interest and talent in their future career.

Figure 3 shows the growth trajectory of publications following Winarno et al.'s (2017) publication. Although there were no publications in 2018, a rapid increase occurred from 2019 to 2021. Presumably, the trend will continue in 2022 as the number of publications in August reaches more than half of the previous year. This finding illustrates the growth of Indonesian researchers' interest in this field, which also means an increased need for STEM education implementation and development for PSTs in Indonesia.

Regarding publisher distribution, we found that only a few publishers published our corpus. In international databases, 12 of 14 of the selected articles were published as conference proceeding articles (11 articles in the *Journal of Physics: Conference Series* and one article in *The Institute of Electrical and Electronics Engineers, Inc.*). The remaining two studies were published by Chai et al. (2020) in the *Sustainability Journal* and Wahyu et al. (2020) in the *International Journal of Instruction*. None of the articles was published in international STEM journals. In the Indonesian databases, 17 articles were published in seven of 54 Sinta STEM-related journals. Six articles (Irwanto et al., 2022; Ngabekti et al., 2019; Rokhimawan et al., 2022; Rosana et al., 2021; Rusydiyah et al., 2021; Yulianti et al., 2022) were found in *The Indonesian Journal of Science Education*–the only SCOPUS listed Sinta 1 journal in our corpus. 11 articles were published in Sinta 2 journals, consisting of five in *The Journal of Research in Science Education*, two in *The Aksioma Journal*, one in *The*

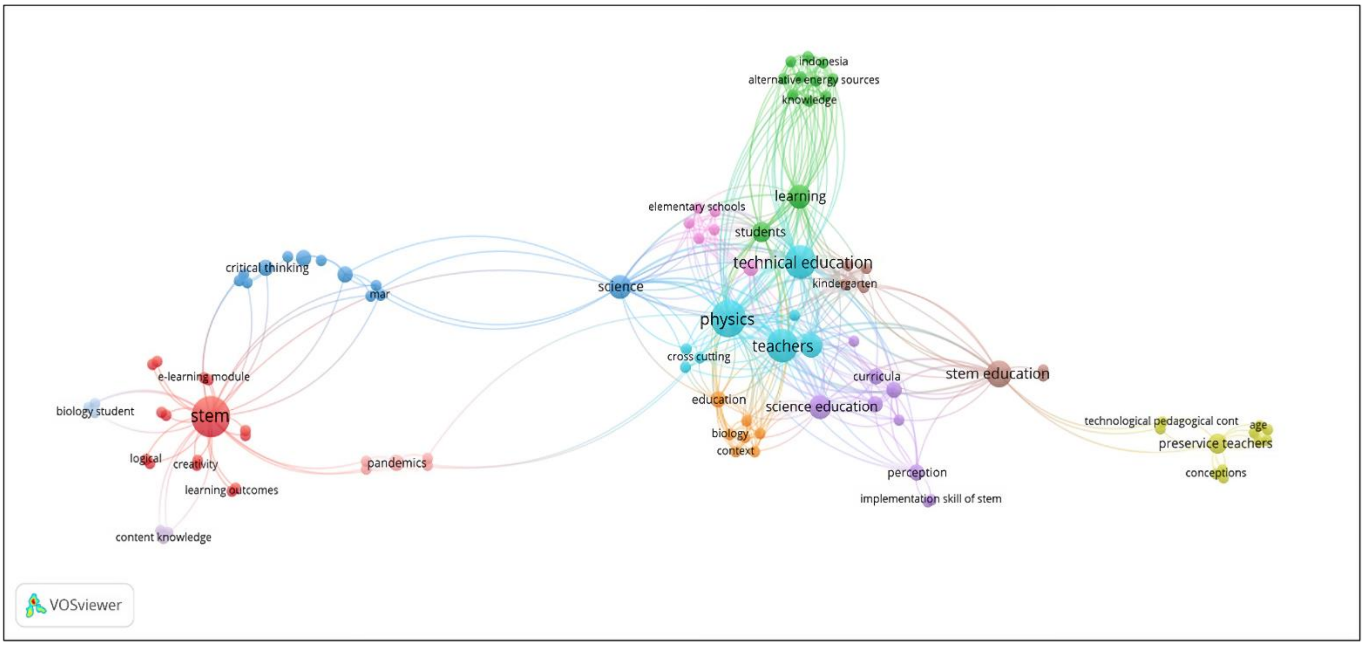

Figure 4. Research topics in STEM education for Indonesian PSTs (Source: Authors' own elaboration)

Education Journal: Theory, Research, and Development, one in *The Eduscience Journal*, one in *The Physics Education Journal*, and one in *The Mosharafa: Mathematics Education Journal*. This finding indicates that Indonesian researchers submit their research to reputable publishers at the local and international levels to improve the quality of STEM implementation and development for Indonesian PSTs.

Indonesian researchers have broad research topic interests, as shown in **Figure 4**. 105 keywords appeared in our corpus and were analyzed with VOSviewer software (Van Eck & Waltman, 2010). The size of the circle illustrates how frequently the keywords were used (the more often it appears, the bigger the circle size), the link of each keyword indicates relatedness (the closer the location of the keywords, the more frequently they are used together in the article), and the color determines the cluster as the most closely related keywords. Clusters collect recurring keywords in publications and can be used to identify the trending topic covered in the literature (Hernández-Torrano & Courtney, 2021). The map shows the three most trending topic clusters: STEM, physics, and technical education. The keyword STEM emphasizes that their study focuses on STEM implementation and development. In contrast, physics keyword indicates the subject discipline that dominates STEM education for PSTs (on research participant background and real-life context researchers used).

Technical education illustrates the engineering process as one of the characteristics of STEM education. The map demonstrates life skills, competence (critical thinking, logical thinking, content knowledge and creativity), and pedagogy aspects (STEM teaching, learning, curricula, media, and assessment). Diverse research topics show potential for developing and implementing STEM education with Indonesian PSTs.

Author(s)

110 researchers wrote the 31 selected articles. Most articles are co-authored (97%), with the Nasrudin et al. (2020) article involving a collaboration of eight researchers from five universities. Regarding co-authorship, Rasyid was the researcher with the most co-authors–12 across two articles, Nasrudin et al. (2020) and Rasyid et al. (2021) indicating a wide collaboration base. All of the 110 researchers published at most 1 article as first author. The authors in our corpus published at most two articles, either one as the first author or both as co-authors. Winarno (in Mayasari et al., 2019 and Winarno et al., 2017) and Susilawati (in Rokhimawan et al., 2022 and Rusydiyah et al., 2021) are two other researchers who published two articles. Nevertheless, although it could be assumed that there are currently no particular researchers dominating the Indonesian field, the number of researchers involved and the collaboration that has been established have become the embryo for the development of STEM implementation and research for PSTs in Indonesia.

Participant(s)' discipline background

12 of the 31 articles (39%) involved participants from different disciplines, giving rise to two or more disciplines as collaboration. 15 different discipline backgrounds were found among participants, as shown in **Table 1**. 10 studies involved science and physics PST, and six involved mathematics, biology, and primary school PSTs. Research that only occupied participants in one discipline predominantly involved physics PST. Irwanto et al. (2022) examined PST perception of TPACK

Table 1. Research participants' discipline background

Research participant(s)	Article(s)
Early childhood PST	Rasyid et al. (2021)
Elementary/primary school PST	Amiruddin et al. (2021), **Jannah et al. (2021)**, **Putra et al. (2021)**, Rokhimawan et al. (2022), Sumirat (2019), & Wahyu et al. (2020)
Science PST	**Chai et al. (2020)**, Djulia and Simatupang (2021), **Fakhrudin et al. (2021)**, **Ngabekti et al. (2019)**, **Putra et al. (2021)**, **Rifandi et al. (2020)**, Rusydiyah et al. (2021), Shofiyah et al. (2022), **Widiastuti et al. (2020)**, & Winarno et al. (2017)
Mathematics PST	**Arifanti et al. (2021)**, **Chai et al. (2020)**, **Irwanto et al. (2022)**, **Putri and Feriyanto (2020)**, **Rifandi et al. (2020)**, & Utomo et al. (2020)
Biology PST	**Fakhrudin et al. (2021)**, **Irwanto et al. (2022)**, **Ismet et al. (2020)**, Kurniati et al. (2020), **Ngabekti et al. (2019)**, & **Putra et al. (2021)**
Physics PST	Azhar et al. (2022), Elfa Sari et al. (2021), **Irwanto et al. (2022)**, **Ismet et al. (2020)**, Mayasari et al. (2019), **Putra et al. (2021)**, **Sukma et al. (2022)**, **Widiastuti et al. (2020)**, Wildani and Budiyono (2022),& Yulianti et al. (2022)
Chemistry PST	**Irwanto et al. (2022)**, **Ismet et al. (2020)**, **Putra et al. (2021)**, & **Widiastuti et al. (2020)**
Computer science PST	**Chai et al. (2020) & Widiastuti et al. (2020)**
Engineering PST	**Chai et al. (2020)**
Educational technology PST	**Irwanto et al. (2022)**
Electronic engineering PST	**Irwanto et al. (2022)**
Culinary PST	**Irwanto et al. (2022)**
Informatics & computer engineering PST	**Irwanto et al. (2022)**
Non-PST	Asri et al. (2021) & Rosana et al. (2021)
Expert or lecturer	**Arifanti et al. (2021)**, **Jannah et al. (2021)**, Nasrudin et al. (2020), **Putri and Feriyanto (2020)**, & **Sukma et al. (2022)**

Note. **Bold** font indicates research involving participants with multi-discipline backgrounds

(technological pedagogical content knowledge) for future STEM-related careers involving 8 PST disciplines.

Five studies involved university lecturers as research participants. Nasrudin et al. (2020) is the only study engaging just lecturers as participants. Five studies (Arifanti et al., 2021; Jannah et al., 2021; Ngabekti et al., 2019; Putri & Feriyanto, 2020; Sukma et al., 2022) engage lecturers as experts to validate STEM worksheets, learning media and modules. We included two studies in our corpus not involving PST as additional research that indicates STEM education in Indonesia is emerging for non-PST students. Asri et al. (2021) implemented STEM through project-based learning for physics students, and Rosana et al. (2021) conducted research with natural science students.

The diversity of the research participants indicates the expansion of STEM education in various disciplines at tertiary institutions in Indonesia, particularly for PSTs. In addition, many studies involving cross-disciplinary participants show a promising development in interdisciplinary learning as one of the characteristics of STEM education.

Research location

'Research location' in this study refers to the research participants' Higher Education Institution (HEI) affiliation and province location. 21 of the 31 articles list their HEI affiliation, five report only the HEI affiliation, and five studies fail to mention affiliation or location.

HEI affiliation of eight of 10 articles not identifying participant institution could be inferred based upon author(s) affiliation. For instance, Djulia and Simatupang (2021), Rasyid et al. (2021), and Shofiyah et al. (2022) did not mention the institution and location of their participants. Still, since all the authors have the same affiliation, it suggests that the participants come from the same institution as the authors. In other articles, Fakhrudin et al. (2021), Mayasari et al. (2019), Widiastuti et al. (2020), Winarno et al. (2017), and Rokhimawan et al. (2022) only mentioned HEI locations, but, given that the author's affiliation comes from these locations, it was also inferred that the participants come from the authors' institutions. Hence, we identified 31 HEI from 15 provinces across Indonesia involved in STEM education research, as shown in **Figure 5**.

STEM education for PSTs has yet to be researched equally across Indonesia. Most studies were conducted on Java Island with 17 publications (from the Jakarta, West Java, Central Java, East Java, and Yogyakarta provinces), followed by Sumatera Island (from the Lampung, South Sumatera, Jambi, West Sumatera, Riau, Medan, and Aceh provinces) with 12 publications. STEM implementation for PSTs has not been reported on from the two largest islands in Indonesia (Papua and Kalimantan). Public universities account for 71% of the researchers' affiliations. Three patterns emerged from the 31 identified HEI affiliations: 17 generic institutions, 13 Islamic-based institutions and one Catholic-based institution. Four studies conducted their research in more than one institution, as reported by Rokhimawan

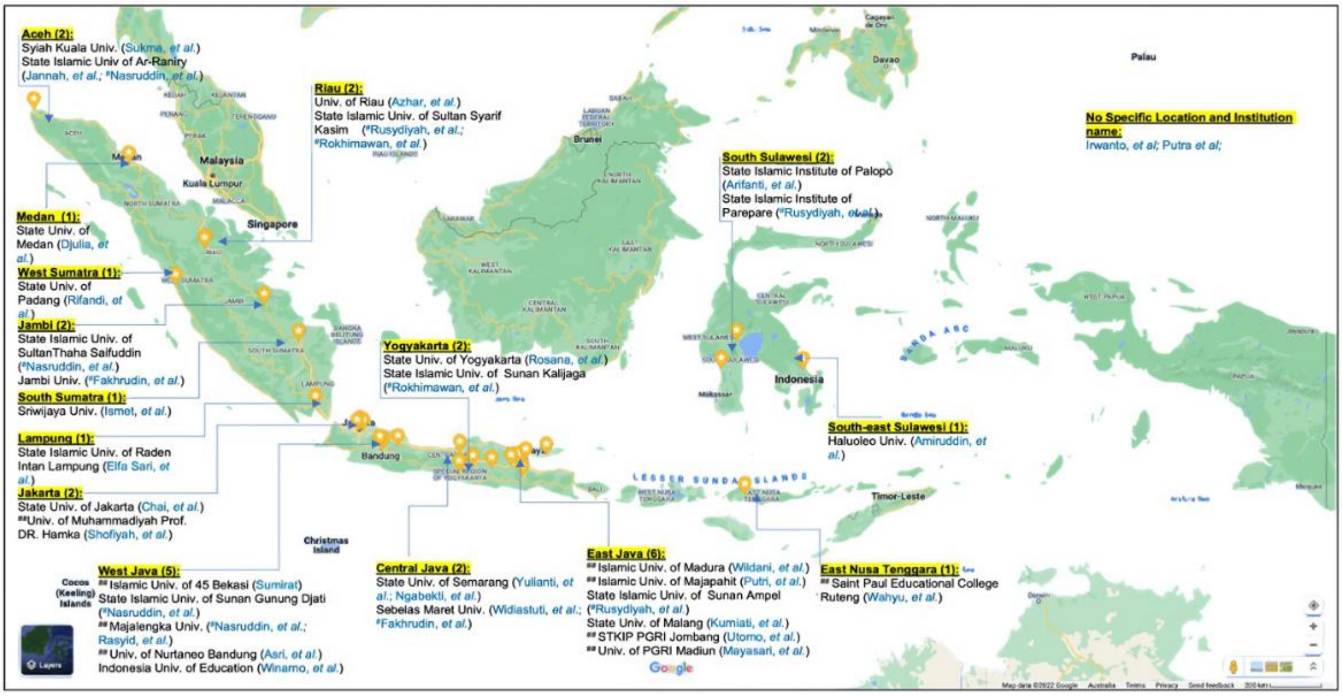

Figure 5. Indonesian STEM research affiliations & location (# indicates research conducted in more than one institution & ## indicates private university) (Source: Authors' own elaboration)

et al. (2022), who implemented their research at two HEI, Rusydiyah et al. (2021) at three HEI, Fakhrudin et al. (2021) at two HEI, and Nasrudin et al. (2020) at four HEI. Although STEM education for PSTs has not been reported on from all provinces in Indonesia (15 out of 37 provinces), the involvement and collaboration across Indonesian universities show a promising growth of STEM education for PSTs in Indonesia.

Research focus

Figure 6 shows the classification of the articles into three STEM research areas. The inner ring refers to the STEM research area (intervention, conceptualization, and development), the middle ring refers to the research focus, and the outer ring refers to the life domain, object or product. In what follows, we explain the findings from each research area.

STEM intervention

STEM interventions were conducted through classroom learning activities, workshops, internships, and field studies. Most researchers used the STEM approach with project-based learning. PSTs had increased science literacy skills (Amiruddin et al., 2021) and STEM content knowledge, particularly science content knowledge, followed by engineering, technology and mathematics content knowledge (Mayasari et al., 2019). The project-based learning STEM approach has promising implications for PSTs to create projects as teaching materials (Djulia & Simatupang, 2021) and improve learning outcomes, even if conducted in an online learning setting (Asri et al., 2021). Other articles show STEM improves problem-solving skills of PSTs (Wildani & Budiyono, 2022) and develops logical reasoning skills (Utomo et al., 2020). Four articles report a positive effect through STEM learning using simple experimental work to increase learning outcomes (Azhar et al., 2022), crosscutting concepts to improve the awareness of science learning and experimentation (Sumirat, 2019), Scratch applications to develop 21st-century skills (critical and creative thinking, collaboration, and communication skills (Yulianti et al., 2022), and mobile augmented reality in enhancing science literacy and achievement (Wahyu et al., 2020).

Other researchers applied STEM interventions beyond the classroom. Chai et al. (2020) conducted a workshop activity for PSTs from different disciplines to collaborate in designing a STEMQuest learning website. This intervention enhanced STEM-related TPACK efficacies. Rusydiyah et al. (2021) found that a PST STEM teaching internship program increased the perception and skills. STEM interventions conducting field study activities (Rosana et al.,2021) through the application of NA-AOGS (natural animal audio organic growth system) technology (with soybean crops) enhances science process skills and critical thinking skills.

Indonesian researchers agree that STEM interventions positively impact research participants in traditional classroom settings, workshops, internships, and field study activities. However, in multi-disciplinary group discussions, the PSTs encountered difficulties expressing their subject-specific topic knowledge and contextualizing and applying it to real-world problems (Chai et al., 2020). Problem-solving abilities in STEM

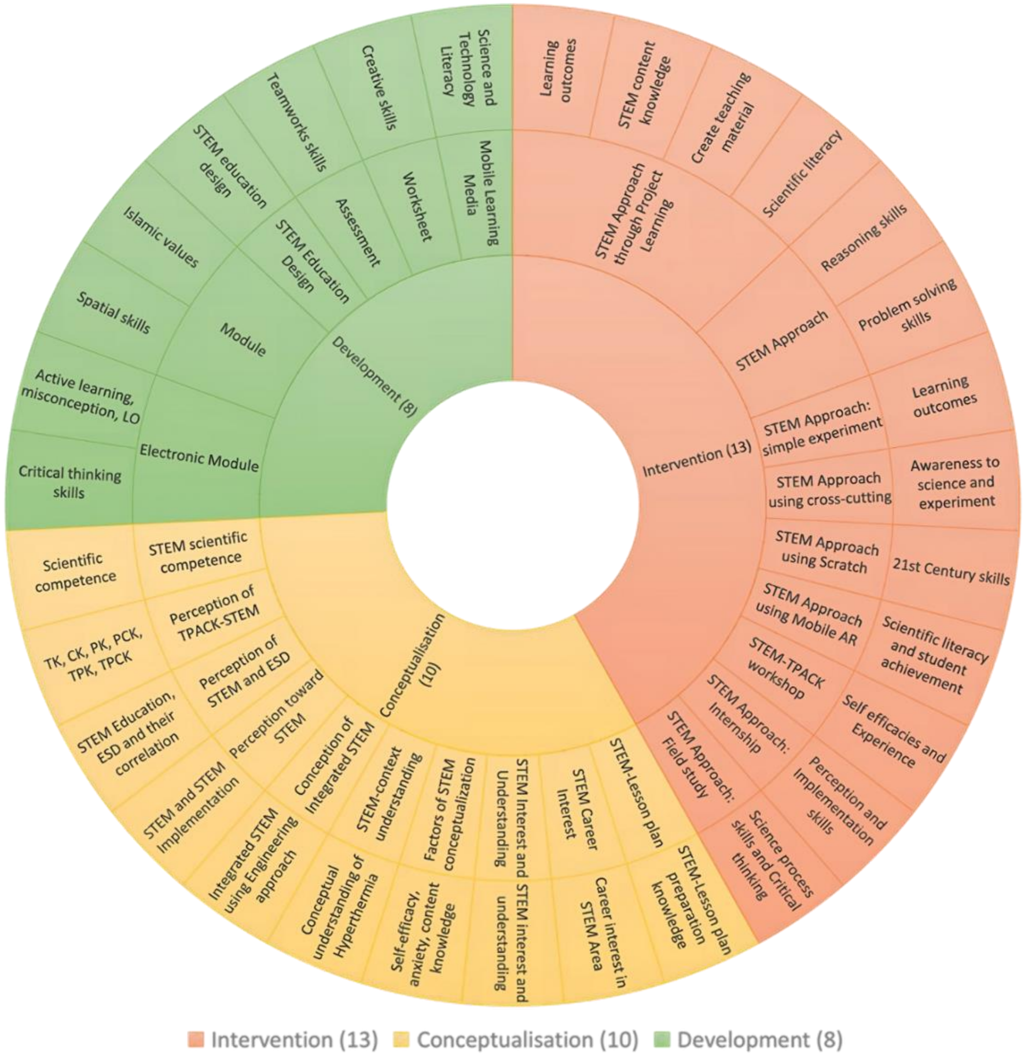

Figure 6. Classification of STEM education research for PST in Indonesia: Intervention, conceptualization, & development (Source: Authors' own elaboration)

improves academic accomplishment (Wildani & Budiyono, 2022).

STEM conceptualization

10 of the 31 articles in the corpus focused on conceptualization of STEM-related aspects, such as STEM perception, interest, conception, and STEM-learning preparation skills. Indonesian PSTs have a positive perception of STEM education (Rifandi et al., 2020), including a perception of TPACK needed as a future STEM teacher (Irwanto et al., 2022) and a perception of STEM education for sustainable development (ESD) (Fakhrudin et al., 2021). Furthermore, Indonesian PSTs concur that STEM education could be adopted at every school level and undertaken in all subjects (Rifandi et al., 2020). Regarding STEM-related interest, Indonesian PSTs were reported to fascinate by STEM education learning (Kurniati et al., 2020) and are interested in being involved in a STEM-related career when they graduate (Winarno et al., 2017). Indonesian PSTs tend to have good intentions and motivation to implement and develop STEM education, benefiting STEM education development in Indonesia.

Researchers report that Indonesian PSTs need more knowledge and competence in STEM conception and understanding. They struggled to describe integration across the STEM disciplines (Widiastuti et al., 2020), had difficulty in identifying and connecting the concepts from different disciplines into a multidiscipline context (Ismet et al., 2020), and lacked scientific competence regarding the STEM approach (Rokhimawan et al., 2022). Researchers noticed that this occurred due to limited exposure to engineering design during pedagogical coursework (Widiastuti et al., 2020), classroom activities not designed for context-based learning, and they do not have prior knowledge related to the context (Ismet et al., 2020). Putra et al. (2021) report that STEM conceptualization was influenced by science content knowledge, self-efficacy, and anxiety. Content knowledge is essential to integrate STEM subjects and improve STEM self-efficacy. Another article reported an investigation into PSTs preparing lesson plans on STEM

Table 2. STEM-DiMRECS framework

Framework dimensions	Description
Discipline ***i***ntegration	Integrate STEM disciplines (Glancy & Moore, 2013) with transparent & equitable connections (English, 2016) through interdisciplinary approaches (Vasquez et al., 2013)
Multiple representations	Providing learning experiences through various communication & representation modes (Jolly, 2017; Vasquez et al., 2013) & translation across those modes (Glancy & Moore, 2013)
Realistic & relevant problems	Using projects (Glancy & Moore, 2013) that relate to real-life problems (Glancy & Moore, 2013; Jolly, 2017; Vasquez et al., 2013) as a learning context
Engineering design process	Linking STEM disciplines through engineering design process (English, 2016), defining problems, researching/gathering information, imagining possible solutions, planning, creating, testing & evaluating the solutions, redesigning, & communicating solutions (English, 2016; Jolly, 2017).
Collaboration	Encouraging students to work collaboratively as a community of learners (Glancy & Moore, 2013; Jolly, 2017; Vasquez et al., 2013).
Student-centered learning	Placing students at center of learning (English, 2016; Jolly, 2017) through hands-on inquiries using grade-appropriate content, challenges, & contexts (Jolly, 2017; Vasquez et al., 2013).

learning. The study revealed that PSTs consider enjoyable STEM learning experiences essential to promoting students' understanding (Rasyid et al., 2021).

STEM development

STEM development for PSTs in Indonesia focuses on enhancing learning media, assessment, and education programs. Modules (in electronic and conventional form) are the most commonly developed learning media that improve PSTs' skills, engagement and learning outcomes. These reduce misconceptions (Sukma et al., 2022), nurture critical thinking skills (Elfa Sari et al., 2021), improve spatial skills (Putri & Feriyanto, 2020), and introduce Islamic values in daily life (Jannah et al., 2021). Other developmental media include mobile learning applications to enhance science and technology literacy (Ngabekti et al., 2019) and worksheets to improve creative thinking skills (Arifanti et al., 2021). STEM development was also conducted to assess teamwork skills (Shofiyah et al., 2022) and education design. Nasrudin et al. (2020), through the collaboration of eight researchers from five different institutions, promote five strategies to teach STEM to PSTs:

(1) incorporate STEM learning into one lecture topic,

(2) use STEM learning in pedagogical techniques,

(3) offer specialized STEM courses,

(4) conduct STEM projects across departments, and

(5) establish STEM centers.

How is STEM Education for Pre-Service Teachers Being Implemented in Indonesia?

In this section, we conduct an integrative review to analyze how the academic community has implemented and understood STEM Education for PSTs in Indonesia. As academics' interest in this field grew, our analysis of the scholarly literature revealed the diverse understanding and implementation of STEM education, including the integration of STEM disciplines, student engagement, the use of context and content, student involvement and activity in the learning process.

We adapted four theoretical frameworks to develop a framework to guide our integrated STEM learning review analysis. Glancy and Moore (2013) provided five theoretical foundations for effective STEM learning environments based on Dewey, Dienes, and Lesh; Jolly (2017) introduced eight criteria to develop STEM programs and learning practices; Vasquez et al. (2013) established five STEM guiding principles to conduct and develop STEM lessons; and English (2016) recommended four aspects to advance STEM as integrated learning. We noticed that these four frameworks are interrelated, reinforcing the implementation and development of STEM education.

Table 2 summarizes STEM-DiMRECS framework, developed to ensure the research analysis of our corpus would guide STEM education for Indonesian PST.

Discipline integration

Discipline integration is the first essential characteristic of STEM learning, as the abbreviation of STEM itself arises as the amalgamation of science, technology, engineering, and mathematics. Integrating these disciplines offers the opportunity to comprehend issues through rich, engrossing, and profound experiences in natural and realistic contexts (Glancy & Moore, 2013). To integrate STEM disciplines, Vasquez et al. (2013) propose three approaches that can be implemented at any education level: multidisciplinary, interdisciplinary and transdisciplinary. English (2016) recommends nurturing 21st-century skills that advance STEM integration lifting the profile of the disciplines and interdisciplinary connections. The STEM-DiMRECS framework proposes disciplinary integration by assimilating STEM disciplines with more transparent and equitable links through multidisciplinary, interdisciplinary, or transdisciplinary approaches.

Regarding the discipline's integration aspect, we noticed three article types in our corpus: articles explaining integration of each STEM discipline, articles indicating STEM integration without explanation, and articles that did not provide an integration description.

Table 3. STEM integration

Papers	STEM discipline			
	Science	Technology	Engineering	Mathematics
Arifanti et al. (2021)	Information exploration regarding problems	Using technology (e.g., GeoGebra)	Build mathematical models	Solving problems using graph & simplex methods
Chai et al. (2020)	Interdisciplinary science inquiry	Technology support for coding	Designing & making items	Mathematical modelling
Elfa Sari et al. (2021)	Understanding concept of thermometers	Types of thermometers	Designing thermometers	Understanding & applying temperature conversions
Mayasari et al. (2019)	Heat, airflow, electricity, & energy conversion concepts	Convert light energy into electrical energy	Design & create solar cracker dryers	Geometry & angles in solar dryer
Rosana et al. (2021)	Sound waves in living systems	Using Arduino & sound applications	Design create NA-AOGS devices	Growth rate/frequency sound pattern
Utomo et al. (2020)	Information exploration	Determining problem-solving software	Operating software	Analyzing & convey ideas
Yulianti et al. (2022)	Parabolic motion, momentum, & impulse	Using Scratch application	Develop simulation	Algorithm thinking

In the first group, seven articles describe STEM integration, as shown in **Table 3**.

Table 3 supports the idea that STEM integration is understood differently. Researchers view STEM integration as a:

- technique to explore and understand a phenomenon or concept through each STEM discipline–Yulianti et al. (2022) used scratch application technology to create simulations to describe and understand an idea.
- learning syntax consisting of science, technology, engineering and mathematics processes sequentially–Utomo et al. (2020) used a STEM approach intervention to enhance reasoning skills and Arifanti et al. (2021) developed a STEM worksheet.
- interdisciplinary spaces that connect STEM disciplines to solve a problem–Chai et al. (2020) used integration to create a STEMQuest, Rosana et al. (2021) applied STEM in a transdisciplinary manner to a real-world issue.

Seven articles demonstrated STEM integration without explaining the contribution of each STEM discipline. Four articles encouraged product design (Amiruddin et al., 2021; Asri et al., 2021; Djulia & Simatupang, 2021) and crosscutting concepts (Sumirat, 2019) involving multiple disciplines. Three articles saw STEM integration as STEM-based learning media development involving a real-life context. For instance, a house construction as a learning context in geometry module (Putri & Feriyanto, 2020), planaria hunting in Semarang river in ecosystem mobile learning media (Ngabekti et al., 2019), and Skydiving in a Newtons Law module (Jannah et al., 2021). Although these articles describe learning process activities and develop STEM media, they must integrate STEM disciplines.

17 articles did not discuss the integration of each STEM discipline. Some articles focus on the outcomes of the intervention without explanation regarding the learning process. For example, internship programs to develop STEM perception and implementation skills (Rusydiyah et al., 2021), STEM approaches to enhance problem-solving skills (Wildani & Budiyono, 2022), and STEM-based learning using mobile augmented reality to increase scientific literacy and knowledge achievement (Wahyu et al., 2020). Others focus on validation process of product (Shofiyah et al., 2022; Sukma et al., 2022). Most STEM integration in our corpus focused on one discipline (science dominates), while technology and engineering roles tend to be complementary. Three articles integrated all STEM disciplines to make an interdisciplinary STEM-based learning media by Chai et al. (2020), Mayasari et al. (2019), and Rosana et al. (2021) to solve community problems.

Multiple representations

Providing multiform experiences and giving students opportunities to communicate their ideas in various ways is an essential STEM integration element. Glancy and Moore (2013) mentioned that the interactions experienced by students would affect their current and future experiences. Interactions provide opportunities to share challenges, knowledge, expertise, results, and skills through communication (Jolly, 2017) with multiple outcomes (Vasquez et al., 2013). Glancy and Moore (2013) mentioned representations are written reports, symbols, diagrams, concrete models, experience based metaphors, and spoken language. Students need exposure to various representations and translations to gain the highest level of conceptual understanding. STEM-DiMRECS uses multiple representations with different communication approaches and translations between representational modes.

Table 4. Topic & context

Main topic	Real-life context
Biology	Ecosystem, planaria hunting in Semarang River (Ngabekti et al., 2019)
Biophysics	Soybeans productivity & growth (Rosana et al., 2021)
Mathematics	Geometry, house construction (Putri & Feriyanto, 2020) & linear program, housing development (Arifanti et al., 2021)
Physics	Electricity, home electricity instalment (Asri et al., 2021); mechanics, parabolic ball motion, collision (Yulianti et al., 2022); Newtons law, skydiving (Jannah et al., 2021); solar cell (Sukma et al., 2022); solar cell, cracker dryer (Mayasari et al., 2019); & heat, thermometer (Elfa Sari et al., 2021)
Science	STEMQuests: exoskeleton; wind-turbine generator; building materials; green building; piezoelectric; nano-generator; fruits as alternative energy, recycled plastic waste (Chai et al., 2020); science projects: electric broom; simple mixer; mini vacuum cleaner; air conditioner recharger; blender; earth rotation; locomotive, mini generator (Djulia & Simatupang, 2021); balloons (Rasyid et al., 2021); rocket, catapult, paper bridge (Sumirat, 2019); human transportation system (Wahyu et al., 2020); energy (Putra et al., 2021); hyperthermia (Ismet et al., 2020)

No article in our corpus explicitly discussed multiple representations. Various representations were implied. Most participants experience four representation modes: diagrams, concrete models, written text, and spoken language. Participants design and create projects or devices, write reports or orally present their findings or products (Amiruddin et al., 2021; Asri et al., 2021; Azhar et al., 2022; Djulia & Simatupang, 2021; Mayasari et al., 2019; Rosana et al., 2021; Sumirat, 2019). Other participants create graphs, simulations, learning web-based media (symbol, diagram, and picture mode representation), explain products verbally, and then report in written form (Chai et al., 2020; Utomo et al., 2020; Yulianti et al., 2022). In STEM-based media development, participants create diagrams (Arifanti et al., 2021), conduct observations (Ngabekti et al., 2019) and create projects or experiments (Elfa Sari et al., 2021; Jannah et al., 2021). Five articles have participants feel experience-based metaphors allowing a choice of project or design to create (Chai et al., 2020; Djulia & Simatupang, 2021; Sumirat, 2019), then solve real-life community problems (Mayasari et al., 2019; Rosana et al., 2021).

Realistic and relevant problem

Problems, challenges, or projects involving multi-discipline knowledge are characteristic of STEM learning. STEM problems are not fragmented issues of science, technology, engineering, or mathematics but are interdisciplinary, where students use interdisciplinary knowledge while problem-solving. The problems must be complex and reflect issues that students face in their personal lives (Glancy & Moore, 2013) revealing the relevance and usefulness of STEM learning (Vasquez et al., 2013). 17 articles in our corpus use real-life issues as their problems, challenges, or research topics. Science contexts are the most common, followed by physics, mathematics, biology, and biophysics (**Table 4**).

Projects, common phenomena, or daily activities, and real-world community problems allow participants to think, learn, and integrate knowledge and skills across STEM disciplines. Projects engage participants in design thinking to create products like 3D models of home electrical installations (Asri et al., 2021) and simple thermometers. Common phenomenon or activity from daily life as a context are used, e.g. a river ecosystem (Ngabekti et al., 2019) or housing construction and development (Arifanti et al., 2021; Putri & Feriyanto, 2020). Authentic community problems develop solutions, such as increasing soybean productivity (Rosana et al., 2021) and decreasing drying time of crackers utilizing solar energy (Mayasari et al., 2019).

The problem or challenge needs to be realistic and doable to engage participants in the learning process and give a positive response to the developed learning media. Some researchers provide opportunities for their participants to determine the real-life problems to investigate (Chai et al., 2020; Djulia & Simatupang, 2021; Sumirat, 2019), increasing the personal experience.

Engineering design process

The engineering design process (EDP) plays a crucial role in STEM education by linking and integrating each STEM discipline. Jolly (2017) defined the engineering design process as a systematic, orderly, open-ended way of approaching problems and designing solutions by integrating and applying science, mathematics, and technology concepts. Jolly (2017) outlines an eight-step EDP: define, research, imagine, plan, create, test, and evaluate, redesign and communicate. English (2016) mentioned three core elements to the EDP: defining problems, generating and evaluating solutions, and optimizing solutions. Although different, both English (2016) and Jolly (2017) agree that EDP steps are an iterative process to develop the best solution. In STEM learning, students employ EDP to create a model, prototype, or product that addresses their problem. Our STEM-DiMRECS framework offers an EDP that defines a problem, research information, imagines the solution, plans, creates, tests and evaluates, redesigns, and communicates the solution.

Table 5. Learning process steps

Author(s)	Learning process steps/stages
Mayasari et al. (2019)	Identifying, exploring, ideating, analyzing, designing, prototyping, testing & data collection, improving, & presenting
Djulia and Simatupang (2021)	Discussing, presenting, researching, preparing, designing, reviewing, developing, & finalizing
Rosana et al. (2021)	Defining, designing, demonstrating, evaluating, developing, & communicating
Chai et al. (2020)	Lecturing, discussing, tweaking, presenting, reviewing, & refining
Amiruddin et al. (2021)	Reflecting, researching, discovering, applying, & communicating

Table 6. Collaboration types

Type of collaboration	Participant discipline's background
Single-discipline collaboration	Physics PST (Azhar et al., 2022; Mayasari et al., 2019; Yulianti et al., 2022); science PST (Djulia & Simatupang, 2021); elementary school PST (Amiruddin et al., 2021; Jannah et al., 2021; Sumirat, 2019); & physics (non-PST) (Asri et al., 2021)
Multi-discipline collaboration	PST: science, mathematics, computer science, & engineering (Chai et al., 2020)
Collaboration with community	Natural science (non-PST) & soybean farmer (Rosana et al., 2021)

No articles in our corpus explicitly mentioned the EDP to generate the best solution in STEM learning. Most researchers describe the learning process in three phases: preparation (define the problemand explore information), generating or creating the solution, and reporting the solution, both written and oral. Five articles provided a step process to create a solution (**Table 5**).

In **Table 5**, the researchers conduct different process steps to generate the solution, however they all include some form of iterative process for design improvement.

Collaboration

To Glancy and Moore (2013), realistic and interdisciplinary problems are solved by teams, with team members have differing expertise. Students approach problem-solving in groups, working together as a community of learners. Vasquez et al. (2013) argue that tomorrow's workers are expected to have teamwork, collaboration, and 21st-century abilities. In STEM learning, students must work in groups to plan, develop, and produce prototypes, test and analyze the results and improve the solution (Jolly, 2017).

Ten articles in our corpus explicitly mention collaboration. We found three types of collaboration (**Table 6**): in single-discipline collaboration, participants in the same fieldwork collaboratively to solve the problem through group discussion (Amiruddin et al., 2021; Asri et al., 2021; Azhar et al., 2022; Djulia & Simatupang, 2021; Jannah et al., 2021; Mayasari et al., 2019; Sumirat, 2019; Yulianti et al., 2022). In multi-discipline collaboration, participants from different fields work to solve the problem. For example, Chai et al. (2020) combine PSTs from four disciplines. Collaboration with the community includes society members in the project to help understand and solve the authentic problem; for example, Rosana et al. (2021) included soybean farmers in their project.

Researchers all require participants to work in groups to address the problems. We suggest a partnership that combines diverse expertise and involves community members since it will provide more comprehensive views and ideas for solving problems. Group members learn from each other enriching knowledge and skills, and involving society members provides authentic problems and enhances personal experiences and empathy.

Student-centered learning

Student-centered learning is an essential aspect of STEM learning developing knowledge, attitudes, and life skills for the future; the learning process should involve student-centered activities (English, 2016; Jolly, 2017), use inquiry-based approaches that feature hands-on investigations using grade-appropriate content, contexts, and problems (Jolly, 2017; Vasquez et al., 2013).

In learning content, researchers in our corpus employed content grade-level appropriate to participants; some articles explicitly mentioned objectives and competency standards (Arifanti et al., 2021; Azhar et al., 2022; Jannah et al., 2021; Ngabekti et al., 2019). Although participants developed solutions to issues or challenges, some had difficulties addressing the tasks, communicating their discipline-based content knowledge, contextualizing and connecting their content knowledge with real-world design challenges, and describing integration (Chai et al., 2020; Ismet et al., 2020). Researchers provided various hands-on activities e.g. creating models, simulations or devices (Amiruddin et al., 2021; Asri et al., 2021; Chai et al., 2020; Djulia & Simatupang, 2021; Mayasari et al., 2019; Rosana et al., 2021; Sumirat, 2019; Yulianti et al., 2022), conducting experiments (Azhar et al., 2022; Elfa Sari et al., 2021; Jannah et al., 2021) or doing field observations (Ngabekti et al., 2019). Researchers in our corpus reported that hands-on activity encourages participants to participate actively in the learning process.

DISCUSSION AND CONCLUSION

STEM education gains popularity due to its positive impact on students' development of attitude, knowledge, and various future-related abilities. Researchers identify teachers having a central role in STEM education's success (Bell et al., 2018; Keane & Keane, 2016; Park et al., 2016; Saat et al., 2021; Suebsing & Nuangchalerm, 2021). Teacher preparation for STEM learning must be conducted, particularly for PSTs to create STEM-ready teachers for the future. In the Indonesian context, the development of STEM education is growing at all levels of education (Farwati et al., 2021; Thao et al., 2020) and is thus essential for PST study.

This study sought to map and provide comprehensive information regarding the movement of STEM education for Indonesian PSTs (**RQ1**). We found research was initially published in 2017, demonstrating how recent STEM education research for Indonesian PSTs is.. To date, researchers have yet to emerge as experts in this field. 110 authors across 31 articles, and the collaboration among them has become the embryo for the development of STEM implementation and research for Indonesian PSTs in the future.

An upsurge in publications occurred in the past three years and is predicted to continue since the Indonesian government recently began to promote STEM education by establishing various programs and partnerships (MoEC, 2018, 2020b). They also launched STEM learning as one of the key agendas of SEAMEO-QITEP (MoEC, 2021). These programs encourage HEI in Indonesia and the academic community to keep their eyes on STEM education. Some universities have established STEM centers, (see for example: Indonesia University of Education [http://stemedcenter.upi.edu] and State University of Semarang [https://mipa.unnes.ac.id/v3/tag/stem]).

The diversity of participants' backgrounds and distribution of research locations across Indonesia is interesting. 15 disciplines were involved as research participants, with 39% of articles reporting multi-discipline backgrounds combining two or more disciplines or collaborating with professionals or lecturers. This finding indicates a good sign for STEM education development as a learning approach that integrates knowledge and skills of STEM disciplines borderless (Jolly, 2017; Vasquez et al., 2013). Regarding the research location, 31 HEI from 15 provinces across Indonesia conducted STEM education research, with public universities leading the research. 31 HEI locations concentrate on Java and Sumatra Islands, and they come from generic, Islamic, and Catholic institutions. This phenomenon is understandable as the Java and Sumatra islands, respectively, constitute the foremost and second-most inhabited islands in Indonesia (Statistics, 2021), and additionally possess the highest number of HEI in the country (MoEC, 2020a). Moreover, these two islands are the first and second-highest scoring island on the national English test (MoEC, 2019). Inhabitants of these two islands thus can communicate internationally, also acquire global information and knowledge, including STEM education materials. This can be seen from the many international references researchers use in our corpus.

Although STEM education for PSTs is conducted in less than half of Indonesian provinces, the involvement and collaboration across HEI and of the research participants show that STEM education in Indonesia is emerging inclusively.

The current study explored research focus, trending topics and publishers. The 105-keyword analysis across articles revealed the words STEM, physics, and technical education as the most mentioned in the corpus. The corpus articles were published in international and local databases, mostly in international proceedings and second-grade local journals. Three research focus areas were found. First, STEM intervention refers to articles that focus on conducting a STEM approach in the learning process and its impact on their research participant. 13 articles reported STEM intervention in the form of classroom-based learning, workshop, internship, and field study activities using the STEM approach, all reporting a positive impact on knowledge and skills. This finding aligns with global academic research, which indicates that participation in STEM learning benefits learners, including improved learning outcomes and attitudes towards learning, creativity, and the acquisition of 21st-century skills (Amalya et al., 2021; Celiker, 2020; Chen & Chen, 2021; Oschepkov et al., 2022; Sheffield et al., 2017; Yildirim, 2016). Academics agree that STEM education could provide a rich learning experience by giving opportunities to learn and address more related and relevant real-world problems by integrating the disciplines (Bybee, 2013; English, 2016; Glancy & Moore, 2013; Vasquez et al., 2013). Second, STEM conceptualization with an intervention-free focus emerged. Ten articles said STEM perception, interest, conception, and STEM-learning preparation skills relating to STEM learning. Indonesian PSTs have good STEM perception, interest, and motivation to implement and develop STEM learning experiences. However, they still need more knowledge, conception, and competence to implement STEM education. Researchers found that some factors contributed to this phenomenon, including inadequate exposure to engineering design concepts, context-free learning activities in the classroom, and a lack of prior knowledge pertaining to the subject topic (Ismet et al., 2020; Widiastuti et al., 2020). Third, eight articles reported STEM development for Indonesian PSTs as STEM-based learning media, assessment, and education programs. Modules, worksheets, mobile-learning press, review, and a STEM program were developed to establish STEM education in tertiary settings to enhance student competencies in scientific literacy, critical and creative thinking and teamwork. This diverse range of research topics demonstrates the potential for the development and implementation of STEM education for Indonesian PSTs in the future.

The second question we explored was to investigate how the academic community implemented and understood STEM education for Indonesian PSTs. To do this, we proposed a STEM-DiMRECS framework. This framework is integration based aimed at STEM learning for PSTs. We employed the framework to analyze 31 articles in our corpus. The STEM-DiMRECS integrated review findings are:

Discipline integration exhibits three different perceptions regarding STEM integration: as a method to investigate and comprehend a phenomenon or notion using each STEM subject, as a learning syntax, and as an interdisciplinary space that combines each STEM discipline to solve a problem or challenge. Additionally, most STEM integration focuses on Science with Technology and Engineering as complementary. This could happen because STEM learning does not appear explicitly in the Indonesian Education curriculum, which has led to various viewpoints in the academic community regarding how STEM should be applied and developed. Moreover, in the global community, the STEM concept and definition itself have become vast and varied (Hasanah, 2020; Tan & Kidman, 2021).

Multiple representations still need to be explicitly discussed four types of representations are utilized: diagrams, concrete models, written reports, and spoken language. Multiple representations are essential to provide multiform experiences and various ways to communicate ideas in the learning process. These representations could accommodate the participants' different learning preferences and optimize multiple outcomes. Glancy and Moore (2013) mentioned that participants are more likely to comprehend a concept when it is represented in various ways and with more embodiments.

Real and relevant problems are real-life issues generally include constructing simple projects, common phenomena, and real-world community problems to encourage thinking, learning, and integrating knowledge and skills. Even though researchers use various types of real-life contexts, all researchers indicated that the problem or challenge is realistic enough and doable to engage their participants to be actively involved in the learning process. Glancy and Moore (2013) mentioned that the problem in STEM learning is not that it should be real in an absolute meaning, or that students must have a personal experience about it, but that the crucial point is that the context should be realistic enough, feasible and believable. Hence, the student feels a personal-experience connection to the context.

Engineering design process describes the different processes and possible provision of a step-by-step guide to problem-solving. Although the researchers in our corpus applied different EDP process steps, all researchers involved participants preparing, generating and reporting the solutions to problems. Moreover, all of them involved an iterative process aimed at improving the design. The process aligns with the EDP characteristic that involves a systematic, orderly, open-ended, and iterative process to gain the best possible solution (English, 2016; Jolly, 2017).

Collaboration in our framework means encouraging students to work collaboratively as a community of learners. Ten articles in the corpus state a collaborative work among their participants. In general, there are three types of collaboration: single-discipline, multi-discipline, and community collaboration. In all kinds of collaboration, researchers reported that participants work together to solve problems. However, we suggest conducting multi-discipline collaboration involving community participants is the best combination of collaboration work to learn from each other and to solve real-world problems. Involving multi-discipline backgrounds, participants in the learning process are provided with an opportunity to share ideas, perspectives, skills, and a way of thinking to solve the problem comprehensively (Glancy & Moore, 2013; Golding, 2009; Power & Handley, 2019).

Student-centered learning places students as a learning center through hands-on investigations using appropriate grade content, challenge, and context. In the corpus, researchers stated they employ appropriate grade content, context, and challenge for their participants. This is an important aspect in STEM learning provided the learning tasks are neither too simple that participants become bored, nor too challenging that participants give up (Jolly, 2017; Vasquez et al., 2013). Moreover, researchers provide a variety of hands-on activities in the form of constructing a project, doing experimental work and field observation.

STEM education for PSTs must be developed further. We recommend that the academic community continues to work collaboratively across HEIs. In addition, we notice that scholars have different views and understanding in implementing and developing STEM education for PSTs in Indonesia and the international community. To establish more systematic and effective STEM learning, we proposed the STEM-DiMRECS framework for implementing and developing integrated STEM learning. The framework consists of six aspects: integrating STEM disciplines with more transparent and equitable connections, providing a learning experience through a variety of communication and representation, using a more realistic and relevant issue that relates to real-world problems as a learning context, uses the engineering design process to generate the best solution to address the problem, engages participants to work together as a learning community, and places the participant at the center of learning through hands-on activities with appropriate content, context, and challenge.

Author contributions: MGN, GK, & HT: contributed to generating idea, determined study goals, formulated research question, designed methodology, & reviewed manuscript; **MGN:** collected, interpreted, analyzed, & drafted original manuscript; & **GK & HT:** supervised process, verified, & validated results, & reviewed & edited manuscript. All authors have agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Acknowledgments: The authors would like to thank Indonesia Endowment Fund for Education (Lembaga Pengelola Dana Pendidikan, LPDP), Ministry of Finance, & Republic of Indonesia who supported Muhamad Gina Nugraha, first author, through a doctoral scholarship program.

Ethical statement: Authors stated that the article did not require any ethical approval.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Amalya, C. P., Artika, W., Safrida, S., Nurmaliah, C., Muhibbuddin, M., & Syukri, M. (2021). Implementation of the problem base learning model combined with E-STEM based student worksheets on learning outcomes and self efficacy on environmental pollution materials. *Jurnal Penelitian Pendidikan IPA* [*Science Education Research Journal*], *7*, 37-38. https://doi.org/10.29303/jppipa.v7iSpecialIssue.962

Ayaz, E., & Sarikaya, R. (2019). The effect of engineering design-based science teaching on the perceptions of classroom teacher candidates towards STEM disciplines. *International Journal of Progressive Education*, *15*(3), 13-27. https://doi.org/10.29329/ijpe.2019.193.2

Bartels, S. L., Rupe, K. M., & Lederman, J. S. (2019). Shaping preservice teachers' understandings of STEM: A collaborative math and science methods approach. *Journal of Science Teacher Education, 30*(6), 666-680. https://doi.org/10.1080/1046560X.2019.1602803

Bell, D., Morrison-Love, D., Wooff, D., & McLain, M. (2018). STEM education in the twenty-first century: learning at work–an exploration of design and technology teacher perceptions and practices. *International Journal of Technology and Design Education, 28*(3), 721-737. https://doi.org/10.1007/s10798-017-9414-3

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*(1), 30.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. National Science Teachers Association–NSTA Press.

Celiker, H. D. (2020). The effects of scenario-based STEM project design process with pre-service science teachers: 21st century skills and competencies, integrative STEM teaching intentions and STEM attitudes. *Journal of Educational Issues, 6*(2), 451-477. https://doi.org/10.5296/jei.v6i2.17993

Chen, K., & Chen, C. (2021). Effects of STEM inquiry method on learning attitude and creativity. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(11), em2031. https://doi.org/10.29333/ejmste/11254

Council, E. (2015). *National STEM school education strategy: A comprehensive plan for science, technology, engineering and mathematics education in Australia*. https://www.education.gov.au/australian-curriculum/support-science-technology-engineering-and-mathematics-stem/national-stem-school-education-strategy-2016-2026

English, L. D. (2016). STEM education K-12: perspectives on integration. *International Journal of STEM Education*, *3*, 3. https://doi.org/10.1186/s40594-016-0036-1

Farwati, R., Metafisika, K., Sari, I., Sitinjak, D. S., Solikha, D. F., & Solfarina, S. (2021). STEM education implementation in Indonesia: A scoping review. *International Journal of STEM Education for Sustainability, 1*(1), 11-32. https://doi.org/10.53889/ijses.v1i1.2

Glancy, A. W., & Moore, T. J. (2013). Theoretical foundations for effective STEM learning environments. *School of Engineering Education Working Papers, 1*. http://docs.lib.purdue.edu/enewp/1

Golding, C. (2009). Integrating the disciplines: Successful interdisciplinary. *Center for the Study of Higher Education, The University of Melbourne*. https://gened.psu.edu/sites/default/files/docs/LOA%20-%20InterdisciplinaryCourse_HowToGuide-Gooding.pdf

Hallinger, P., & Kovačević, J. (2019). A bibliometric review of research on educational administration: Science mapping the literature, 1960 to 2018. *Review of Educational Research*, *89*(3), 335-369. https://doi.org/10.3102/0034654319830380

Hasanah, U. (2020). Key definitions of STEM education: Literature review. *Interdisciplinary Journal of Environmental and Science Education, 16*(3), e2217. https://doi.org/10.29333/ijese/8336

Hernández-Torrano, D., & Courtney, M. G. R. (2021). Modern international large-scale assessment in education: An integrative review and mapping of the literature. *Large-scale Assessments in Education, 9*, 17. https://doi.org/10.1186/s40536-021-00109-1

Hobbs, L., Clark, J. C., & Plant, B. (2018). Successful students–STEM program: Teacher learning through a multifaceted vision for STEM education. In R. Jorgensen, & K. larkin (Eds.), *STEM education in the junior secondary: The state of play* (pp. 133-168). Springer. https://doi.org/10.1007/978-981-10-5448-8_8

Jho, H., Hong, O., & Song, J. (2016). An analysis of STEM/STEAM teacher education in Korea with a case study of two schools from a community of practice perspective. *EURASIA Journal of Mathematics, Science and Technology Education, 12*(7), 1843-1862. https://doi.org/10.12973/eurasia.2016.1538a

Jolly, A. (2017). *STEM by design. Strategies and activities for grades 4-8*. Taylor & Francis.

Keane, L., & Keane, M. (2016). STEAM by design. *Design and Technology Education, 21*(1), 61-82.

Kim, E., Oliver, J. S., & Kim, Y. A. (2019). Engineering design and the development of knowledge for teaching among preservice science teachers. *School Science and Mathematics, 119*(1), 24-34. https://doi.org/10.1111/ssm.12313

MoEC. (2018). *Kemendikbud Gandeng Casio untuk tingkatkan kompetensi siswa bidang sains dan teknologi* [*Ministry of Education and Culture collaborates with Casio to increase student competence in science and technology*]. https://www.kemdikbud.go.id/main/blog/2018/09/kemendikbud-gandeng-casio-untuk-tingkatkan-kompetensi-siswa-bidang-sains-dan-teknologi

MoEC. (2019). *Pusat Penilaian Pendidikan: Laporan hasil ujian nasional* [*Center of Education Assessment: National test report*]. https://hasilun.pusmenjar.kemdikbud.go.id/

MoEC. (2020a). *Higher education statistics*. https://pddikti.kemdikbud.go.id/asset/data/publikasi/Statistik%20Pendidikan%20Tinggi%202020.pdf

MoEC. (2020b). *Kemendikbud Selenggarakan KIHAJAR STEM 2020 wujudkan generasi pelajar Pancasila* [*Ministry of Education and Culture holds KIHAJAR STEM 2020, creating a generation of Pancasila students*]. https://www.kemdikbud.go.id/main/blog/2020/10/kemendikbud-selenggarakan-kihajar-stem-2020-wujudkan-generasi-pelajar-pancasila

MoEC. (2021). *Dukungan tujuh SEAMEO centres bagi kebijakan merdeka belajar dan kampus merdeka* [*Support of seven SEAMEO centers for independent learning and independent campus policy*]. https://www.kemdikbud.go.id/main/blog/2021/02/dukungan-tujuh-seameo-centres-bagi-kebijakan-merdeka-belajar-dan-kampus-merdeka

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine, 151*(4), 264-269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

Ng, A., Kewalramani, S., & Kidman, G. (2022). Integrating and navigating STEAM (inSTEAM) in early childhood education: An integrative review and inSTEAM conceptual framework. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(7), em2133. https://doi.org/10.29333/ejmste/12174

Noh, A. M., & Khairani, A. Z. (2020). Validating the S-STEM among Malaysian pre-university students. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *9*(3), 421-429. https://doi.org/10.15294/jpii.v9i3.24109

Nugroho, O. F., Permanasari, A., Firman, H., & Riandi, R. (2021). The urgency of STEM education in Indonesia. *Jurnal Penelitian dan Pembelajaran IPA* [*Journal of Science Research and Learning*], *7*(2), 260-279. https://doi.org/10.30870/jppi.v7i2.5979

Nurwahyunani, A. (2021). Literature review: A STEM approach to improving the quality of science learning in Indonesia. *Journal for the Education of Gifted Young Scientists, 9*(5), 11-17. https://doi.org/10.17478/jegys.853203

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

Ozkaya, A. (2019). Bibliometric analysis of the publications made in STEM education area. *Bartın Üniversitesi Eğitim Fakültesi Dergisi* [*Bartin University Journal of the Faculty of Education*], *8*(2), 590-628. https://doi.org/10.14686/buefad.450825

Park, H., Byun, S.-Y., Sim, J., Han, H.-S., & Baek, Y. S. (2016). Teachers' perceptions and practices of STEAM education in South Korea. *EURASIA Journal of Mathematics, Science and Technology Education, 12*(7), 1739-1753. https://doi.org/10.12973/eurasia.2016.1531a

Power, E., & Handley, J. (2019). A best-practice model for integrating interdisciplinarity into the higher education student experience. *Studies in Higher Education, 44*(3), 554-570. https://doi.org/10.1080/03075079.2017.1389876

Radloff, J., & Guzey, S. (2016). Investigating preservice STEM teacher conceptions of STEM education. *Journal of Science Education and Technology, 25*(5), 759-774. https://doi.org/10.1007/s10956-016-9633-5

Ritz, J. M., & Fan, S.-C. (2015). STEM and technology education: International state-of-the-art. *International Journal of Technology and Design Education, 25*(4), 429-451. https://doi.org/10.1007/s10798-014-9290-z

Roberts, A., & Cantu, D. (2012). Applying STEM instructional strategies to design and technology curriculum. In *Proceedings of the PATT 26 Conference: Technology Education in the 21st Century*.

Saat, R. M., Fadzil, H. M., Adli, D. S. H., & Awang, K. (2021). STEM teachers' professional development through scientist-teacher-students partnership (STSP). *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *10*(3), 357-367. https://doi.org/10.15294/jpii.v10i3.27845

Sharma, G. (2019). Innovation and entrepreneurship research in India from 2000 to 2018: A bibliometric survey. *Journal of Management Development, 38*(4), 250-272. https://doi.org/10.1108/jmd-11-2018-0316

Sheffield, R., Koul, R., Blackley, S., & Maynard, N. (2017). Makerspace in STEM for girls: A physical space to develop twenty-first-century skills. *Educational Media International, 54*(2), 148-164. https://doi.org/10.1080/09523987.2017.1362812

Statistics. (2021). *Population density by province*. https://www.bps.go.id/indicator/12/141/1/kepadatan-penduduk-menurut-provinsi.html

Suebsing, S., & Nuangchalerm, P. (2021). Understanding and satisfaction towards STEM education of primary school teachers through professional development program. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *10*(2), 171-177. https://doi.org/10.15294/jpii.v10i2.25369

Tan, H., & Kidman, G. (2021). Authentic assessment in STEM education: An integrative review of research. In T. Barkatsas, & P. McLaughlin (Eds.), *Authentic assessment and evaluation approaches and practices in a digital era* (pp. 24-52). BRILL. https://doi.org/10.1163/9789004501577_002

Thao, T. T. P., Ha, C. T., Trung, N. T., Huong, L. T. T., Dinh, N. V., & Trung, T. (2020). A bibliometric review of research on STEM education in ASEAN: Science mapping the literature in Scopus Database, 2000 to 2019. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(10), em1889. https://doi.org/10.29333/ejmste/8500

Toronto, C. E., & Remington, R. (2020). *A step-by-step guide to conducting an integrative review*. Springer. https://doi.org/10.1007/978-3-030-37504-1

Torraco, R. J. (2005). Writing integrative literature reviews: Guidelines and examples. *Human Resource Development Review, 4*(3), 356-367. https://doi.org/10.1177/1534484305278283

Toto, T., Yulisma, L., & Amam, A. (2021). Improving teachers' comprehension and readiness in implementing STEM through science learning simulation. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *10*(2), 303-310. https://doi.org/10.15294/jpii.v10i2.27509

Triwahyuningtyas, D., Sundaygara, C., Widiaty, I., Nandiyanto, A., Aji, S., & Hudha, M. (2021). Bibliometric analysis of the term 'STEM module'. *IOP Conference Series: Materials Science and Engineering, 1098*(3), 032031. https://doi.org/10.1088/1757-899x/1098/3/032031

Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics, 84*(2), 523-538. https://doi.org/10.1007/s11192-009-0146-3

Vasquez, J. A., Sneider, C. I., & Comer, M. W. (2013). *STEM lesson essentials, grades 3-8: Integrating science, technology, engineering, and mathematics*. Heinemann.

Worldbank. (2022). *The World Bank in Indonesia: Overview*. https://www.worldbank.org/en/country/indonesia/overview#1

Yildirim, B. (2016). An analyses and meta-synthesis of research on STEM education. *Journal of Education and Practice, 7*(34), 23-33.

Zulaikha, D. F., Jumadi, J., Mardiani, A., & Lutfia, B. A. (2021). The development of physics learning research with STEM approach in Indonesia: A content analysis. *Edusains, 13*(2), 138-152. https://doi.org/10.15408/es.v13i2.18766

Zupic, I., & Čater, T. (2014). Bibliometric methods in management and organization. *Organizational Research Methods, 18*(3), 429-472. https://doi.org/10.1177/1094428114562629

APPENDIX

Table A1. List of articles used in the review

Article
Amiruddin, B., Budi, A. S., & Sumantri, M. S. (2021). Enhancing science literacy capabilities of prospective primary school teachers through the STEM project learning model. *Journal of Physics: Conference Series, 1869*, 012176. https://doi.org/10.1088/1742-6596/1869/1/012176
Arifanti, D. R., Thalhah, S. Z., Mafidapuspadina, M., & Muzaini, M. (2021). Pengembangan lembar kerja peserta didik berbasis STEM untuk meningkatkan kemampuan kreativitas matematika [Development of STEM-based student worksheets to improve mathematical creativity abilities]. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika* [*AKSIOMA: Journal of the Mathematics Education Study Program*], *10*(4), 2710-2725. https://doi.org/10.24127/ajpm.v10i4.4258
Asri, Y. N., Mursyidah, D. S., & Rizqi, V. (2021). Application of project-based learning through a STEM approach to improve learning outcomes during a pandemic. *Jurnal Penelitian Pendidikan IPA* [*Science Education Research Journal*], *7*(4), 719-722. https://doi.org/10.29303/jppipa.v7i4.819
Azhar, A., Irawan, D., & Ramadhan, K. (2022). STEM education implementation to enhance student learning outcomes in optics concept. *Jurnal Penelitian Pendidikan IPA* [*Science Education Research Journal*], *8*(2), 1023-1029. https://doi.org/10.29303/jppipa.v8i2.1525
Chai, C. S., Rahmawati, Y., & Morris Siu-Yung, J. (2020). Indonesian science, mathematics, and engineering preservice teachers' experiences in STEM-TPACK design-based learning. *Sustainability, 12*(21), 9050. https://doi.org/10.3390/su12219050
Djulia, E., & Simatupang, H. (2021). STEM-based project for everyday life created by pre service students and its implication of pedagogical competence for science teacher. *Journal of Physics: Conference Series, 1819*, 012012. https://doi.org/10.1088/1742-6596/1819/1/012012
Elfa Sari, H., Yuberti, Saregar, A., & Wildaniati, Y. (2021). Development of STEM-integrated physics e-module to train critical thinking skills: The perspective of preservice teachers. *Journal of Physics: Conference Series, 1796*, 012100. https://doi.org/10.1088/1742-6596/1796/1/012100
Fakhrudin, I. A., Wicaksana, E. J., Nastiti, A. R., Saljadziba, E., & Indriyanti, N. Y. (2021). Pre-service teachers' perspectives: STEM as a solution to promote education for sustainable development. *Journal of Physics: Conference Series, 1842*, 012082. https://doi.org/10.1088/1742-6596/1842/1/012082
Irwanto, I., Redhana, I. W., & Wahono, B. (2022). Examining perceptions of technological pedagogical content knowledge (TPACK): A perspective from Indonesian pre-service teachers. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *11*(1), 142-154. https://doi.org/10.15294/jpii.v11i1.32366
Ismet, Darmawijayo, Aisyah, N., Nawawi, E., Yusup, M., & Meilinda. (2020). How to support pre-service teachers' conceptual understanding using hyperthermia as STEM context: A case study in sciences education department Universitas Sriwijaya. *Journal of Physics: Conference Series, 1480*, 012072. https://doi.org/10.1088/1742-6596/1480/1/012072
Jannah, M., Oviana, W., & Nurhalizha, I. (2021). Pengembangan modul ipa berbasis Islamic science technology engineering and mathematics pada materi hukum Newton [Development of IPA modules based on Islamic science technology engineering and mathematics on Newton's law material]. *Edusains, 13*(1), 83-94. https://doi.org/10.15408/es.v13i1.13805
Kurniati, E., Suwono, H., & Ibrohim, I. (2020). Analisis profil pemahaman dan ketertarikan mahasiswa biologi pada STEM education [Profile analysis of biology students' understanding and interest in STEM education]. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan* [*Journal of Education: Theory, Research, and Development*], *5*(12), 1732-1737. https://doi.org/10.17977/jptpp.v5i12.14310
Mayasari, T., Susilowati, E., & Winarno, N. (2019). Practicing integrated STEM in renewable energy projects: Solar power. *Journal of Physics: Conference Series, 1280*, 052033. https://doi.org/10.1088/1742-6596/1280/5/052033
Nasrudin, D., Rochman, C., Suhendi, H. Y., Helsy, I., Rasyid, A., Aripin, I., Utami, W., & Mayasri, A. (2020). STEM education for pre-service teacher: Why and how? *Journal of Physics: Conference Series, 1563*, 012039. https://doi.org/10.1088/1742-6596/1563/1/012039
Ngabekti, S., Prasetyo, A., Hardianti, R., & Teampanpong, J. (2019). The development of stem mobile learning package ecosystem. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *8*(1), 81-88. https://doi.org/10.15294/jpii.v8i1.16905
Putra, P. D. A., Ahmad, N., Wahyuni, S., & Narulita, E. (2021). Analysis of the factors influencing of pre-service science teacher in conceptualization of STEM education: Self-efficacy and content knowledge. *Jurnal Penelitian Pendidikan IPA* [*Science Education Research Journal*], *7*(Special Issue), 225-230. https://doi.org/10.29303/jppipa.v7iSpecialIssue.877
Putri, R. O. E., & Feriyanto, F. (2020). Pengembangan bahan ajar geometri berbasis science technology engineering and mathematics (STEM) untuk mendukung kemampuan spasial [Development of science technology engineering and mathematics (STEM) based geometry teaching materials to support spatial abilities]. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika* [*AKSIOMA: Journal of the Mathematics Education Study Program*], *9*(4), 1205-1212. https://doi.org/10.24127/ajpm.v9i4.3141

Table A1 (Continued). List of articles used in the review

Article
Rasyid, A., Sugandi, M. K., Gaffar, A. A., Jatisunda, M. G., Santoso, E., & Nahdi, D. S. (2021). Teaching STEM through play in kindergarten: Analysis towards pre-service early childhood teachers preparing the lesson plan. *Journal of Physics: Conference Series, 1764*, 012130. https://doi.org/10.1088/1742-6596/1764/1/012130
Rifandi, R., Rahmi, Y. L., Widya, & Indrawati, E. S. (2020). Pre-service teachers' perception on science, technology, engineering, and mathematics (stem) education. *Journal of Physics: Conference Series, 1554*, 012062. https://doi.org/10.1088/1742-6596/1554/1/012062
Rokhimawan, M. A., Yuliawati, F., Kamala, I., & Susilawati, S. (2022). Prospective madrasah teachers' scientific competencies integrated with scientific literacy through the STEM approach. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *11*(1), 91-103. https://doi.org/10.15294/jpii.v11i1.32983
Rosana, D., Kadarisman, N., Purwanto, A., & Sari, E. K. (2021). The effect of learning biophysics with STEM approach on science process skills and critical thinking: Field study on application of NA-AOGS for increasing soybean productivity and growth rate. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *10*(3), 447-461. https://doi.org/10.15294/jpii.v10i3.30695
Rusydiyah, E. F., Indarwati, D., Jazil, S., Susilawati, S., & Gusniwati, G. (2021). STEM learning environment: Perceptions and implementation skills in prospective science teachers. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *10*(1), 138-148. https://doi.org/10.15294/jpii.v10i1.28303
Shofiyah, N., Wulandari, F. E., Mauliana, M. I., & Pambayun, P. P. (2022). Teamwork skills assessment for STEM project-based learning. *Jurnal Penelitian Pendidikan IPA* [*Science Education Research Journal*], *8*(3), 1425-1432. https://doi.org/10.29303/jppipa.v8i3.1678
Sukma, M., Halim, A., & Evendi, E. (2022). Implementation of e-learning module based on science technology engineering mathematics on solar cells topic. *Jurnal Ilmu Pendidikan Fisika* [*Journal of Physics Education*], *7*(1), 60-70.
Sumirat, F. (2019). Strategies of teaching: Promoting science technology engineering and mathematics (STEM) education through cross-cutting concepts. *Journal of Physics: Conference Series, 1179*, 012076. https://doi.org/10.1088/1742-6596/1179/1/012076
Utomo, E. S., Rahman, F., & Fikrati, A. N. (2020). Eksplorasi penalaran logis calon guru matematika melalui pengintegrasian pendekatan stem dalam menyelesaikan soal [Exploration of logical reasoning for prospective mathematics teachers through integrating the stem approach in solving problems]. *Mosharafa: Jurnal Pendidikan Matematika* [*Mosharafa: Journal of Mathematics Education*], *9*(1), 13-22. https://doi.org/10.31980/mosharafa.v9i1.574
Wahyu, Y., Suastra, I. W., Sadia, I. W., & Suarni, N. K. (2020). The effectiveness of mobile augmented reality assisted STEM-based learning on scientific literacy and students' achievement. *International Journal of Instruction, 13*(3), 343-356. https://doi.org/10.29333/iji.2020.13324a
Widiastuti, I., Budiyanto, C. W., & Ramli, M. (2020). Pre-service teacher conceptions of integrated STEM using the engineering design approach. In *Proceedings of the 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering* (pp. 106-111). IEEE. https://doi.org/10.1109/TALE48869.2020.9368382
Wildani, A., & Budiyono, A. (2022). Challenge of applying STEM education to improve physics problem solving skills in Islamic boarding schools. *Jurnal Penelitian Pendidikan IPA* [*Science Education Research Journal*], *8*(3), 1231-1235. https://doi.org/10.29303/jppipa.v8i3.1586
Winarno, N., Widodo, A., Rusdiana, D., Rochintaniawati, D., & Afifah, R. M. A. (2017). Profile of pre-service science teachers based on STEM career interest survey. *Journal of Physics: Conference Series, 895*, 012170. https://doi.org/10.1088/1742-6596/895/1/012170
Yulianti, D., Sugianto, S., & Ngafidin, K. M. (2022). Scratch assisted physics learning with a STEM approach in the pandemic era to develop 21st century learning skills. *Jurnal Pendidikan IPA Indonesia* [*Journal of Indonesian Science Education*], *11*(1), 185-194. https://doi.org/10.15294/jpii.v11i1.32607