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Contribution of STEM and STEAM Education to 21st-Century Learning Competencies in Indonesia: A Systematic Literature Review (2015–2025)

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Abstract

STEM and STEAM education have received increasing attention as approaches for developing students' competencies required in 21st-century learning. However, evidence regarding how STEM/STEAM education contributes to these competencies within the Indonesian educational context remains fragmented. This study aims to systematically analyze research trends, implementation patterns, and competency outcomes associated with STEM/STEAM education in Indonesia during 2015-2025. A systematic literature review was conducted following the PRISMA framework using articles retrieved from Google Scholar, Scopus, and ERIC databases. Based on predefined inclusion criteria, 63 articles published in Sinta-indexed and Scopus-indexed journals were selected for analysis. The findings indicate that STEM/STEAM research in Indonesia is predominantly conducted through experimental approaches at the secondary education level, particularly in science learning contexts. Project-based learning, problem-based learning, and inquiry-based learning are the most frequently integrated instructional approaches. The reviewed studies frequently associate STEM/STEAM implementation with the development of critical thinking, scientific literacy, problem-solving skills, and learning outcomes. This review highlights the progress of STEM/STEAM education in Indonesia while identifying research gaps related to teacher readiness, assessment development, interdisciplinary integration, and technology-supported learning.

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1. INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education has emerged as an important educational approach to prepare students with competencies required in the 21st century. Initially introduced by the National Science Foundation (NSF) in the United States during the 1990s, STEM education was developed in response to the increasing demand for human resources with strong scientific literacy, technological capability, and higher-order thinking skills (Caridade, 2020; Arifin et al., 2021). Over time, STEM education has expanded beyond the integration of four disciplines and has been recognized as an interdisciplinary learning approach that promotes critical thinking, problem-solving, creativity, collaboration, and communication skills (Zainil et al., 2023; AlAli, 2024; Vithanage & Nakashima, 2025). The development

of STEM education has also encouraged the emergence of STEAM education, which incorporates arts elements to strengthen creativity and innovation in science and technology learning (Yang, 2023).

The increasing complexity of global challenges and technological transformation in the era of Industry 4.0 have strengthened the need for educational approaches that develop students' 21st-century competencies. In this context, STEM/STEAM education has been considered a potential approach to provide meaningful and authentic learning experiences through problem-solving, inquiry, and project-based activities (Smith et al., 2022; Farwati et al., 2021). Through interdisciplinary learning environments, STEM/STEAM approaches enable students to apply scientific concepts to real-world problems while developing various transferable skills needed for future academic and professional contexts.

In Indonesia, STEM education has received increasing attention since the introduction of early STEM-based learning initiatives, including the development of STEM-oriented teaching materials in science education (Handayani, 2014). This development has been strengthened by educational policies encouraging the integration of STEM approaches into learning practices (Ardwiyanti et al., 2021). Consequently, research on STEM and STEAM education in Indonesia has increased significantly during the last decade, covering various educational levels, science disciplines, instructional strategies, and learning resources. However, the rapid growth of STEM-related publications has not yet been accompanied by a comprehensive understanding of how STEM and STEAM education contribute to the development of 21st-century learning competencies in the Indonesian context.

Previous studies have provided valuable insights into STEM education development in Indonesia. Ardwiyanti et al. (2021) examined STEM research trends in Indonesia during 2015–2020 and identified dominant themes related to learning strategies, teaching materials, and learning media. Farwati et al. (2021) explored STEM education implementation through a scoping review approach, while Arifin et al. (2021) analyzed STEM research trends using bibliometric mapping. Although these studies have contributed to understanding STEM development, most previous reviews primarily focused on publication trends, research characteristics, or general implementation patterns. Limited attention has been given to synthesizing how STEM/STEAM education contributes to specific 21st-century learning competencies, what instructional approaches are commonly implemented, and what research gaps remain within Indonesian educational settings.

Therefore, an updated systematic literature review is needed to provide comprehensive evidence regarding the contribution of STEM and STEAM education to 21st-century learning competencies in Indonesia. This study extends previous reviews by analyzing research published between 2015 and 2025 using stricter inclusion criteria, including articles published in journals indexed by Scopus or accredited at least Sinta 2. In addition, this study synthesizes STEM/STEAM implementation patterns, methodological characteristics, competency outcomes, and future research directions. The findings are expected to provide evidence-based insights for researchers, educators, and policymakers in strengthening STEM/STEAM education implementation in Indonesia.

Based on these considerations, this systematic literature review addresses the following research questions: **RQ1.** What are the publication trends and methodological characteristics of STEM/STEAM education research in Indonesia from 2015 to 2025?

RQ2. How are STEM/STEAM approaches implemented across educational levels and science learning contexts?

RQ3. What 21st-century learning competencies are associated with STEM/STEAM education implementation?

RQ4. What future research directions can be identified to strengthen STEM/STEAM education development in Indonesia?

2. RESEARCH METHOD

2.1. Research Design

This study employed a Systematic Literature Review (SLR) to examine the contribution of STEM and STEAM education to 21st-century learning competencies in Indonesia. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2019). This review did not involve hypothesis testing; instead, research questions guided the process of literature identification, data extraction, and synthesis.

2.2. Data Sources and Search Strategy

The literature search was conducted using three electronic databases: Google Scholar, Scopus, and ERIC. These databases were selected because they provide broad coverage of educational research publications, including national and international studies related to STEM and STEAM education. The search was performed using combinations of the following keywords:

"STEM Education" OR "STEAM Education" AND "STEM Indonesia" OR "STEAM Indonesia"

2.3. Study Selection Process

The study selection process was conducted using PRISMA framework through four stages: identification, screening, eligibility assessment, and inclusion stages. Articles were identified from selected databases, screened based on title and abstract relevance, assessed through full-text evaluation, and selected according to predetermined inclusion and exclusion criteria in Table 1. The article selection process is presented in Figure 1.

2.4. Data Extraction and Coding

Data extraction was conducted using a structured Paper Classification Form (PCF) adapted from Kizilaslan et al. (2012). The extracted information included publication year, journal characteristics, educational level, research method, STEM/STEAM implementation approach, learning context, investigated competencies, and main findings. Content analysis focused on three main aspects aligned with the research questions: 21st-century learning skills, implementation of STEM or STEAM education, and future research directions.

2.5. Data Synthesis and Analysis

The extracted data were analyzed using descriptive statistical analysis and qualitative thematic synthesis. Descriptive analysis was used to identify research trends based on frequencies and percentages, including publication distribution, methodological characteristics, educational levels, instructional approaches, and competency themes. Meanwhile, thematic synthesis was applied to interpret patterns of STEM/STEAM implementation, its contribution to 21st-century learning competencies, and potential directions for future research.

Table 1. Inclusion and Exclusion Criteria

Category	Inclusion Criteria	Exclusion Criteria
Publication type	Peer-reviewed journal articles	Proceedings, books, theses, reports, websites
Journal quality	Sinta ≥ 2 or Scopus-indexed journals	Sinta < 2 or non-indexed journals
Publication year	2015-October 2025	Before 2015
Research context	Conducted in Indonesia	Conducted outside Indonesia
Research focus	STEM or STEAM	Non-STEM/STEAM
Field	Science education (Chemistry, Physics, Biology)	Non-science fields
Participants	Students and/or teachers in formal education	Non-formal education contexts

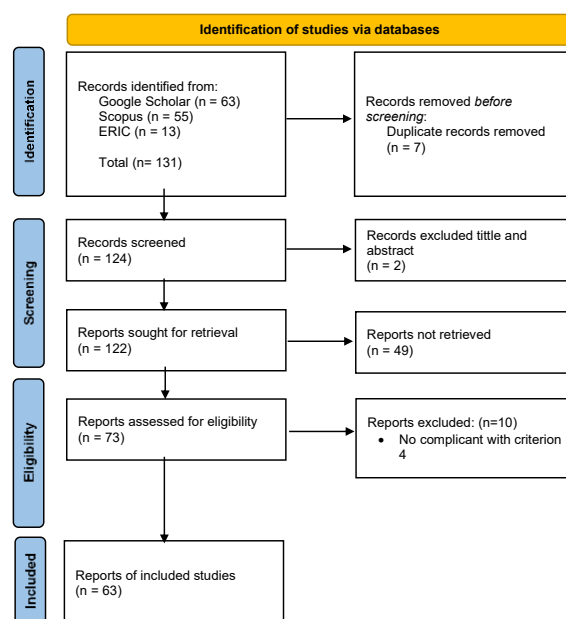


Figure 1. Flowchart PRISMA procedure

3. FINDINGS

3.1. Publication Trends and Research Characteristics

This systematic literature review analyzed 63 selected articles published between 2015 and October 2025 based on inclusion criteria. The characteristics of the selected articles were analyzed based on journal distribution, publication quality, and research sources. Table 2 shows that STEM/STEAM education research

has been published across various nationally accredited and internationally indexed journals. Among the reviewed articles, Jurnal Pendidikan IPA Indonesia represented the highest publication frequency, followed by Jurnal Pendidikan Sains Indonesia and Journal for the Education of Gifted Young Scientists. This finding indicates that STEM/STEAM education research in Indonesia is strongly associated with science education communities, particularly studies focusing on learning innovation, instructional strategies, and science learning improvement.

The research topics in Figure 2 demonstrate that STEM/STEAM studies primarily focus on learning strategies, instructional media, and teaching materials. Meanwhile, studies investigating teacher perceptions, assessment development, and student perspectives remain relatively limited. Research on STEM and STEAM education in Indonesia addresses a range of topics. The most frequently studied areas are learning strategies, followed by learning media and teaching materials. In contrast, teacher perceptions, learning evaluation and assessment, and student perceptions are less commonly explored.

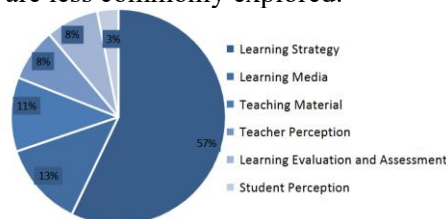


Figure 2. Distribution of research topics in STEM or STEAM education

Table 2. Distribution of Articles using Journal Identification

Type of journal	Rank	Journal Name	Frequency	Percentage (%)
Nasional	Grade 1 (Sinta 1) accredited and Scopus Q2 indexed	Jurnal Pendidikan IPA Indonesia	10	15.9
		Telkomnika	1	1.6
	Grade 2 (Sinta 2) accredited	Jurnal Inovasi Pendidikan IPA	3	4.8
		Jurnal Pendidikan Sains Indonesia	7	11.1
		Jurnal Pendidikan:Teori, Penelitian, dan Pengembangan	3	4.8
		Jurnal Obsesi: Jurnal Pendidikan Anak Usia Dini	4	6.3
		Jurnal Pendidikan Biologi Indonesia (JPBI)	3	4.8
		Jurnal Pendidikan Indonesia	2	3.2
		Journal of Educational Science and Technology	1	1.6
		Premiere Educandum: Jurnal Pendidikan Dasar dan Pembelajaran	2	3.2
		Tadris: Jurnal Keguruan dan Ilmu Tarbiyah	1	1.6
		Jurnal Penelitian Pendidikan IPA	3	4.8
		Jurnal Kependidikan	1	1.6
		Al Bidayah : Jurnal Pendidikan Dasar Islam	1	1.6
		Jurnal Ilmiah Sekolah Dasar	2	3.2
		Jurnal Pendidikan Usia Dini	1	1.6
International	Scopus Q1	Cultural Studies of Science Education	1	1.6
	Scopus Q2	Sustainability	1	1.6
		International Journal of Instruction	1	1.6
	Scopus Q3	Journal for the Education of GiftedYoung Scientists	5	7.9

Type of journal	Rank	Journal Name	Frequency	Percentage (%)
Scopus Q4		European Journal of Educational Research	2	3.2
		Turkish Journal of Computer and Mathematics Education	3	4.8
		International Journal of Environmental & Science Education	1	1.6
		Review of International Geographical Education	1	1.6
		Universal Journal of Educational Research	2	3.2
		International Journal of Evaluation and Research in Education (IJERE)	2	3.2

Table 3. The Trend of STEM or STEAM Education via Research Methodologies

Approach	Research Methods	Frequency	Percentage (%)
Qualitative	Literature Review	2	3.2
	Comparative Study	1	1.6
	Phenomenology	1	1.6
	Descriptive	7	1.1
Quantitative	Experiment	23	36.5
	Survey	8	12.7
The Other	Mixed Method	8	12.7
	Research and Development	12	19.0
	Classroom Action Research	1	1.6

3.2. Research Methodologies in STEM/STEAM Education

Based on Table 3, experimental research was the most frequently applied methodology, accounting for 36.5% of the reviewed studies. The dominance of experimental and development-based studies indicates that STEM/STEAM research in Indonesia has mainly focused on examining the effectiveness of STEM-based interventions and developing STEM-oriented instructional products. In contrast, qualitative approaches, comparative studies, phenomenological studies, and literature reviews were less frequently identified, indicating that further investigation is needed regarding contextual factors, teacher experiences, and challenges in STEM/STEAM implementation.

3.3. STEM/STEAM Contribution to 21st-Century Learning Competencies

Table 4 presents the distribution of themes associated with STEM/STEAM education. The findings indicate that scientific literacy and critical thinking were the most frequently investigated competency themes, each accounting for 18.4% of the identified themes.

Table 4. Distribution of Themes Related to STEM or STEAM Education

No.	Theme	Frequency (%)
1	Mastery concept	6.6
2	High order thinking skills (HOTS)	2.6
3	Scientific literacy	18.4
4	Critical thinking	18.4
5	Scientific thinking	1.3
6	Science process skills	6.6
7	Creativity skills	7.9
8	Student liveliness	1.3
9	Learning interest	1.3
10	Learning outcomes	15.8
11	Technology literacy	1.3
12	Collaboration skills	1.3

No.	Theme	Frequency (%)
13	Attitude	3.9
14	21st century skills	1.3
15	Learning independence	1.3
16	Indigenous science	1.3
17	Problem solving	9.2

These findings demonstrate that STEM/STEAM education research in Indonesia is primarily oriented toward developing higher-order thinking abilities and scientific understanding. STEM/STEAM learning environments emphasize the application of scientific concepts, problem-solving activities, and interdisciplinary learning experiences, which are closely related to the development of 21st-century competencies.

Table 5. Relationship between STEM/STEAM Approaches and 21st-Century Learning Competencies

No.	STEM/STEAM Approach	Integrated Learning Model/Strategy	Identified 21st-Century Competencies	Supporting Studies
1	STEM-based learning	Project-Based Learning (PjBL-STEM)	Scientific literacy, creativity, problem-solving skills, learning outcomes	Afriana et al. (2016); Wardani et al. (2021); Purwaningsih et al. (2020)
2	STEM-based learning	Problem-Based Learning (PBL-STEM)	Critical thinking skills, problem-solving skills, scientific literacy	Hasanah et al. (2021); Parno et al. (2020); Rivai & Yuliati (2018)
3	STEM-based learning	Inquiry-based learning	Critical thinking skills, scientific reasoning, scientific literacy	Isdianti et al. (2021); Pahrudin et al. (2021); Abdurrahman et al. (2019)
4	STEM-based learning	STEM-integrated worksheets and learning materials	Scientific literacy, conceptual understanding, learning outcomes	Sulistiyowati et al. (2018); Khaeroningtyas et al. (2016); Fithri et al. (2021)
5	STEAM-based learning	STEAM Project-Based Learning	Creativity, independence, problem-solving skills	Amalia et al. (2021); Putri & Taqiudin (2021); Adriyawati et al. (2020)
6	STEM-based digital/media learning	Digital multimedia, virtual laboratory, mobile learning, augmented reality	Technology literacy, scientific literacy, learning achievement	Ismail et al. (2016); Hidayati & Irmawati (2019); Wahyu et al. (2020)
7	STEM-Engineering Design Process (STEM-EDP)	Engineering design activities	Problem-solving skills, creativity, career-related competencies	Nurtanto et al. (2020a); Susilo et al. (2019)

The synthesis presented in Table 5 shows that different STEM/STEAM approaches contribute to various 21st-century competencies. Project-based STEM learning was commonly associated with scientific literacy, creativity, and problem-solving skills because students were engaged in designing products and applying knowledge to authentic problems. Meanwhile, problem-based and inquiry-based STEM approaches were frequently related to critical thinking development through investigation, analysis, and evidence-based reasoning.

3.4. Implementation Patterns of STEM/STEAM Education

STEM/STEAM education has been implemented across different educational levels and science disciplines in Indonesia. The reviewed studies indicate that secondary education represents the dominant research context, particularly in science subjects such as physics, chemistry, and biology.

At the elementary level, STEM/STEAM implementation is commonly integrated into thematic learning activities to develop creativity, scientific literacy, and problem-solving abilities. At the secondary level, STEM approaches are frequently combined with science learning models such as project-based learning, problem-based learning, and inquiry learning. Meanwhile, higher education research focuses more on scientific applications, technological integration, and professional competencies.

The implementation of STEM/STEAM education is commonly supported by contextual learning activities, instructional media development, and engineering design processes. These approaches provide opportunities for students to engage in authentic problem-solving and apply knowledge across disciplines.

4. DISCUSSION

4.1. Publication Trends and Research Characteristics

The increasing attention toward STEM and STEAM education research in Indonesia reflects the growing recognition of interdisciplinary learning approaches in science education. The dominance of STEM/STEAM publications within science education journals indicates that STEM integration is mainly positioned as a strategy to enhance science learning through contextual activities, instructional innovation, and interdisciplinary problem-solving.

This finding is consistent with previous review studies. [Ardwiyanti et al. \(2021\)](#) reported that STEM research in Indonesia has primarily focused on learning strategies, teaching materials, and learning media. Similarly, [Farwati et al. \(2021\)](#) identified that STEM implementation in Indonesia was largely developed through classroom-based innovations and instructional practices. These patterns indicate that the development of STEM education in Indonesia remains strongly oriented toward improving classroom learning processes. Several studies included in this review demonstrate this orientation. [Afriana et al. \(2016\)](#) implemented project-based learning integrated with STEM to support students' scientific literacy, while [Khaeroningtyas et al. \(2016\)](#) developed STEM learning activities to strengthen scientific literacy in junior high school science learning. These findings suggest that STEM adoption in Indonesia has been driven by the need to create learning experiences that connect scientific concepts with real-world applications.

However, compared with previous reviews that mainly mapped STEM research trends, this study provides a broader synthesis by examining how STEM/STEAM approaches are associated with the development of specific 21st-century learning competencies and identifying remaining research gaps.

4.2. Research Methodologies in STEM/STEAM Education

The dominance of experimental and research-and-development approaches indicates that STEM/STEAM research in Indonesia is primarily focused on evaluating instructional effectiveness and developing STEM-based learning resources. This tendency is similar to global STEM research trends reported by [Li et al. \(2020\)](#), which showed that experimental studies are commonly used to investigate the implementation and outcomes of STEM education.

Several studies in this review applied development-oriented approaches to produce STEM learning materials and evaluate their educational potential. [Fithri et al. \(2021\)](#), for example, developed STEM-based worksheets to support students' critical thinking skills, while [Widarti et al. \(2020\)](#) developed STEM-PjBL teaching materials assisted by learning videos. Similarly, [Isatunada and Haryani \(2021\)](#) developed STEM-based science learning tools aimed at training students' problem-solving abilities.

Although experimental and development studies provide important evidence regarding STEM implementation, the limited number of qualitative studies suggests that research attention toward contextual factors remains insufficient. STEM implementation is influenced not only by learning models but also by teacher understanding, readiness, and classroom conditions. Studies by [Parmin et al. \(2020\)](#) and [Wahono and Chang \(2019\)](#) highlight that teachers' knowledge, attitudes, and application skills are important aspects in supporting sustainable STEM implementation.

4.3. STEM/STEAM Contribution to 21st-Century Learning Competencies

The reviewed studies indicate that STEM/STEAM education is frequently associated with the development of scientific literacy, critical thinking, problem-solving skills, and creativity. These competencies represent important components of 21st-century learning because STEM activities require students to investigate problems, apply scientific concepts, develop solutions, and evaluate their ideas. The relationship between STEM implementation and scientific literacy is demonstrated in several reviewed studies. [Afriana et al. \(2016\)](#) reported that STEM-integrated project-based learning supported students' scientific literacy development through investigation and product-oriented activities. Similarly, [Ismail et al. \(2016\)](#) found that STEM-based virtual laboratory learning supported scientific literacy by providing opportunities for students to engage in scientific exploration.

Critical thinking development was also frequently associated with problem-based and inquiry-oriented STEM approaches. [Hasanah et al. \(2021\)](#) reported that STEM-integrated problem-based learning supported

students' critical thinking skills through analysis of environmental problems and scientific reasoning activities. In addition, [Isdianti et al. \(2021\)](#) demonstrated that STEM-based inquiry learning was effective in supporting students' critical thinking development.

Problem-solving and creativity were also identified as important outcomes of STEM learning. [Purwaningsih et al. \(2020\)](#) reported that STEM-PjBL and discovery learning approaches were associated with improvements in students' problem-solving skills. Furthermore, STEAM-oriented studies such as [Adriyawati et al. \(2020\)](#) demonstrated that integrating arts elements into STEM learning can support creativity development through contextual project activities.

These findings indicate that STEM/STEAM education contributes to 21st-century competencies through active and interdisciplinary learning experiences. However, current STEM research in Indonesia still focuses more on cognitive competencies, while broader competencies such as communication, collaboration, and technology literacy require further investigation.

4.4. Implementation Patterns and Future Challenges of STEM/STEAM Education

The implementation of STEM/STEAM education in Indonesia is commonly integrated with project-based learning, problem-based learning, and inquiry approaches. These learning models are considered compatible with STEM characteristics because they encourage students to engage with authentic problems, conduct investigations, design solutions, and apply knowledge across disciplines.

Project-based STEM learning has been widely explored because it provides opportunities for students to construct knowledge through meaningful activities. [Afriana et al. \(2016\)](#) showed that STEM-integrated project-based learning supported scientific literacy development, while [Wardani et al. \(2021\)](#) reported that STEM-integrated project learning contributed to scientific literacy development among prospective elementary teachers. Similarly, [Adriyawati et al. \(2020\)](#) found that STEAM project-based learning supported students' scientific literacy through contextual learning activities.

Problem-based STEM learning has also been widely implemented because it emphasizes problem analysis and solution development. [Hasanah et al. \(2021\)](#) reported that STEM-integrated problem-based learning supported critical thinking development, while [Parno et al. \(2020\)](#) showed that PBL-STEM implementation was associated with differences in students' scientific literacy competencies compared with conventional learning. Despite these developments, several challenges remain. STEM/STEAM research in Indonesia is still concentrated in science learning contexts, particularly secondary education. In addition, research focusing on teacher readiness, assessment frameworks, and long-term implementation strategies remains limited. Teacher-related factors are important because STEM integration requires adequate understanding of interdisciplinary connections and appropriate classroom implementation strategies ([Parmin et al., 2020](#); [Wahono & Chang, 2019](#)).

Furthermore, STEAM research remains less developed compared with STEM research. Although STEAM has the potential to strengthen creativity through arts integration, further studies are needed to examine how arts components contribute to interdisciplinary learning outcomes. Therefore, future research should focus on sustainable STEM/STEAM implementation models, teacher professional development, and assessment approaches that capture broader 21st-century competencies.

5. CONCLUSION

This systematic literature review provides an overview of the development and contribution of STEM/STEAM education research in Indonesia from 2015 to 2025. The synthesis of 63 selected studies indicates that STEM/STEAM education is predominantly implemented through project-based learning, problem-based learning, and inquiry-based approaches, particularly in science education contexts. These approaches are frequently associated with the development of 21st-century learning competencies, including scientific literacy, critical thinking, problem-solving skills, creativity, and learning outcomes.

This review highlights that STEM/STEAM education in Indonesia has progressed significantly; however, several research gaps remain, particularly regarding teacher readiness, assessment development, interdisciplinary implementation, and broader STEAM integration. Therefore, future research should focus on developing sustainable STEM/STEAM implementation models that address these challenges and support comprehensive development of 21st-century competencies.

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REFERENCES

- Abdurrahman, A., Ariyani, F., Maulina, H., & Nurulsari, N. (2019). Design and validation of inquiry-based STEM learning strategy as a powerful alternative solution to facilitate gifted students facing 21st-century challenges. *Journal for the Education of Gifted Young Scientists*, 7(1), 33–56.
- Adriyawati, Utomo, E., Rahmawati, Y., & Mardiah, A. (2020). STEAM-project-based learning integration to improve elementary school students' scientific literacy on alternative energy learning. *Universal Journal of Educational Research*, 8(5), 1863–1873.
- Afiana, J., Permanasari, A., & Fitriani, A. (2016). Project-based learning integrated to STEM to enhance elementary school students' scientific literacy. *Jurnal Pendidikan IPA Indonesia*, 5(2), 261–267.
- Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences*, 11(7).
- Agustina, R., Huda, I., & Nurmaliah, C. (2020). Implementasi pembelajaran STEM pada materi sistem reproduksi tumbuhan dan hewan terhadap kemampuan berpikir ilmiah peserta didik SMP. *Jurnal Pendidikan Sains Indonesia*, 8(2), 241–256.
- Ahmad, D. N., Astriani, M. M., Alfahnum, M., & Setyowati, L. (2021). Increasing creative thinking of students by learning organization with STEAM education. *Jurnal Pendidikan IPA Indonesia*, 10(1), 103–110.
- Ahmad, F., Nugroho, D., & A, I. (2015). Rancang bangun alat pembelajaran microcontroller berbasis Atmega 328 di Universitas Serang Raya. *Jurnal PROSISKO*, 2(1), 10–18.
- AlAli, R. (2024). Enhancing 21st-century skills through integrated STEM education using project-oriented problem-based learning. *Geo Journal of Tourism and Geosites*, 53(2), 421–430.
- Amalia, D., Sutarto, J., Kurniawati, Y., & Pranoto, S. (2021). Pengaruh pembelajaran jarak jauh bermuatan STEAM terhadap karakter kreatif dan kemandirian. *Jurnal Obsesi: Jurnal Pendidikan Anak Usia Dini*, 6(3), 1233–1246.
- Anekawati, A., Hidayat, J. N., Abdullah, N., & Matlubah, H. (2021). Structural equation modeling multi-group of science process skills and cognitive in PjBL integrated STEAM learning. *Jurnal Pendidikan Sains Indonesia*, 9(3), 512–527.
- Ardianti, S., Sulisworo, D., Pramudya, Y., & Raharjo, W. (2020). The impact of the use of STEM education approach on the blended learning to improve student's critical thinking skills. *Universal Journal of Educational Research*, 8(3B), 24–32.
- Ardwiyanti, D., Prasetyo, Z. K., & Wilujeng, I. (2021). STEM research trends in Indonesia: A systematic literature review. *Journal of Science Education Research*, 5(1), 38–45.
- Arifin, Z., Sukarmin, & Sarwanto. (2021). Research and trend on STEM education in Indonesia: A systematic review based on bibliometric mapping (2000–2020). *[Journal information incomplete in original manuscript]*, 58(5), 3235–3243.
- Badriyah, N. L., Anekawati, A., & Azizah, L. F. (2020). Application of PjBL with brain-based STEAM approach to improve learning achievement of students. *Jurnal Inovasi Pendidikan IPA*, 6(1), 88–100.
- Baharin, N., Kamarudin, N., & Manaf, U. K. A. (2018). Integrating STEM education approach in enhancing higher order thinking skills. *International Journal of Academic Research in Business and Social Sciences*, 8(7), 810–821.
- Bertrand, M. G., & Namukasa, I. K. (2020). STEAM education: Student learning and transferable skills. *Journal of Research in Innovative Teaching & Learning*, 13(1), 43–56.
- Bukifan, D., Yuliati, L., & Handayanto, S. K. (2020). Penguasaan konsep siswa pada materi termodinamika dalam pembelajaran argument-driven inquiry for STEM education. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan*, 5(8), 1121–1127.
- Caridade, C. M. R. (2020). STEM (science, technology, engineering, and mathematics) education to teach solids of revolution. In *ICERI2020 Proceedings* (pp. 374–381). IATED.
- Debora, R., & Pramono, R. (2021). Implementation of STEM learning method to develop children's critical thinking and problem-solving skills. *Jurnal Pendidikan Anak Usia Dini*, 6(3), 1221–1232.

- Fadhilah, K., Roshayanti, F., & Purnamasari, V. (2021). Profile of thematic learning viewed from STEAM in the 2013 curriculum for grade IV elementary school. *Jurnal Ilmiah Sekolah Dasar*, 5(2), 334–341.
- Fadlina, F., Artika, W., Khairil, K., Nurmaliah, C., & Abdullah, A. (2021). Penerapan model discovery learning berbasis STEM pada materi sistem gerak untuk meningkatkan keterampilan berpikir kritis. *Jurnal Pendidikan Sains Indonesia*, 9(1), 99–107.
- 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.
- Firdaus, F., Subchan, W., & Narulita, E. (2020). Developing STEM-based TGT learning model to improve students' process skills. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 6(3), 413–422.
- Fithri, S., Tenri Pada, A. U., Artika, W., Nurmaliah, C., & Hasanuddin, H. (2021). Implementasi LKPD berbasis STEM untuk meningkatkan keterampilan berpikir kritis peserta didik. *Jurnal Pendidikan Sains Indonesia*, 9(4), 555–564.
- González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st-century skills frameworks: Systematic review. *Sustainability*, 14(3), 1493.
- Hamdu, G., Fuadi, F. N., Yulianto, A., & Akhirani, Y. S. (2020). Items quality analysis using Rasch model to measure elementary school students' critical thinking skill on STEM learning. *JPI (Jurnal Pendidikan Indonesia)*, 9(1), 61.
- Handayani, F. (2014). *Pengembangan lembar kerja siswa (LKS) berbasis science, technology, engineering, and mathematics (STEM) pada materi hidrolisis garam*. Unsyiah.
- Haryanto, Kusuma, W. M., Mutohhari, F., Nurtanto, M., & Suyitno, S. (2021). Innovation media learning: Online project-based learning (O-PBL) on drawing competence in automotive engineering using video on YouTube. *Journal of Physics: Conference Series*, 2111(1).
- Hasanah, Z., Pada, T. U. A., Safrida, Artika, W., & Mudatsir. (2021). Implementasi model problem-based learning dipadu LKPD berbasis STEM untuk meningkatkan keterampilan berpikir kritis pada materi pencemaran lingkungan. *Jurnal Pendidikan Sains Indonesia*, 9(1), 65–75.
- Hidayati, N., & Irmawati, F. (2019). Developing digital multimedia based on STEM learning to improve students' scientific literacy. *Jurnal Pendidikan Biologi Indonesia*, 5(3), 345–352.
- Isatunada, A., & Haryani, S. (2021). STEM-based learning tools development to train students' problem-solving ability. *Jurnal Pendidikan Sains Indonesia*, 9(2), 250–261.
- Isdianti, R., Parmin, P., & Alimah, S. (2021). The effectiveness of STEM-based inquiry learning packages to improving students' critical thinking skill. *Jurnal Pendidikan IPA Indonesia*, 10(2), 250–257.
- Ismail, I., Permanasari, A., & Setiawan, W. (2016). STEM virtual laboratory: An alternative practical media to enhance students' scientific literacy. *Jurnal Pendidikan IPA Indonesia*, 5(2), 200–207.
- Kaniawati, I., Kaniawati, L., & Suwarma, I. R. (2021). Students' perception towards STEM learning implementation in science education. *Journal of Physics: Conference Series*, 1806(1), Article 012034.
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3, Article 11.
- Kementerian Pendidikan dan Kebudayaan Republik Indonesia. (2014). *Peraturan Menteri Pendidikan dan Kebudayaan Republik Indonesia Nomor 103 Tahun 2014 tentang pembelajaran pada pendidikan dasar dan pendidikan menengah*. Kementerian Pendidikan dan Kebudayaan.
- Khaeroningtyas, N., Permanasari, A., & Hamidah, I. (2016). STEM learning in material of temperature and its change to improve scientific literacy of junior high school students. *Jurnal Pendidikan IPA Indonesia*, 5(1), 53–58.
- Kizilaslan, A., Zorluoglu, S. L., & Kizilaslan, M. (2012). A review of science education studies using classification framework. *Journal of Education and Practice*, 3(15), 1–8.
- Kurniati, T., Yusup, M., & Rahman, M. (2020). Analysis of student understanding toward STEM education concept. *Jurnal Pendidikan Sains Indonesia*, 8(4), 541–552.
- Lestari, A. S., Permanasari, A., & Hernani. (2021). The effect of STEM-based blended learning on students' scientific literacy. *Jurnal Pendidikan IPA Indonesia*, 10(3), 412–420.

- Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: A systematic review. *International Journal of STEM Education*, 7, Article 11.
- Lou, S. J., Chou, Y. C., Shih, R. C., & Chung, C. C. (2017). A study of creativity in STEM project-based learning activities. *Asia-Pacific Education Researcher*, 26(3–4), 135–146.
- Lou, S. J., Shih, R. C., Diez, C. R., & Tseng, K. H. (2011). The impact of problem-based learning strategies on STEM learning outcomes. *International Journal of Technology and Design Education*, 21, 1–17.
- Madyani, R., Yamtinah, S., & Utomo, S. B. (2019). The effect of STEM-based problem-based learning on students' creative thinking skills and learning outcomes. *Jurnal Pendidikan IPA Indonesia*, 8(3), 379–386.
- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, 6, Article 2.
- Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A., & PRISMA-P Group. (2019). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, 4, Article 1.
- Muhammad, N., Rahman, A., & Ismail, N. (2020). Teachers' perception and readiness toward STEM implementation in science learning. *Jurnal Pendidikan Sains Indonesia*, 8(2), 200–210.
- Ngabekti, S., Prihatin, J., & Alimah, S. (2019). Development of STEM mobile learning package ecosystem to support science learning. *Journal of Physics: Conference Series*, 1321(3), Article 032045.
- Nuraeni, F., Permanasari, A., & Sopandi, W. (2020). Trend analysis of STEM learning in elementary school science education. *Jurnal Pendidikan Dasar Indonesia*, 5(2), 65–74.
- Nurtanto, M., Pardjono, Sofyan, H., Ramdani, S. D., & Sulaiman, R. (2020). STEM-related vocational education research and competency development. *Journal of Technical Education and Training*, 12(2), 1–12.
- Nurtanto, M., Sofyan, H., Pardjono, & Nurhaji, S. (2021). A review of gamification in education: Trends and future directions. *Education and Information Technologies*, 26, 1–20.
- Pahrudin, A., Irwandani, I., Triyana, R., Fauziah, S., & Ramdani, D. (2021). The analysis of students' scientific literacy skills through STEM-based learning. *Journal of Physics: Conference Series*, 1796(1), Article 012056.
- Parmin, P., Sajidan, S., Ashadi, A., & Sutikno, S. (2020). Indonesian science teachers' views on attitude, knowledge, and application of STEM. *Journal of Physics: Conference Series*, 1567(2), Article 022022.
- Parno, P., Yuliati, L., Ndadari, M. A., & Ali, M. (2020). The effect of problem-based learning-STEM and problem-based learning models on students' scientific literacy skills. *Jurnal Pendidikan IPA Indonesia*, 9(3), 379–388.
- Perdana, R., Apriyanti, D. D., & Putri, R. S. (2021). STEM-based learning implementation to improve students' scientific literacy and problem-solving skills. *Journal of Physics: Conference Series*, 1842(1), Article 012028.
- Priatna, N., Lorenzia, S. A., & Widodo, S. (2020). STEM education implementation in mathematics learning to develop students' critical thinking skills. *Journal of Physics: Conference Series*, 1521(3), Article 032053.
- Purwaningsih, D., Permanasari, A., Redjeki, S., & Rahmawati, I. (2020). The effect of STEM-PjBL and discovery learning on improving students' problem-solving skills. *Jurnal Pendidikan IPA Indonesia*, 9(3), 368–378.
- Putri, R. D., & Taqiudin, A. (2021). The effect of STEAM learning approach on students' creativity and problem-solving skills. *Jurnal Pendidikan IPA Indonesia*, 10(4), 580–589.
- Rahayu, S., Sapriati, A., & Suryanda, A. (2021). STEM-based learning model development to improve science learning outcomes. *Jurnal Pendidikan Sains Indonesia*, 9(4), 601–612.
- Rahmawati, Y., Ridwan, A., & Hadinugrahaningsih, T. (2021). Developing students' creativity through STEM learning approach. *Jurnal Pendidikan IPA Indonesia*, 10(1), 15–25.
- Rivai, A. A., & Yuliati, L. (2018). STEM learning to improve students' critical thinking skills and scientific literacy. *Journal of Physics: Conference Series*, 1097(1), Article 012027.

- Roberts, A., & Cantu, D. (2012). Applying STEM instructional strategies to design and technology curriculum. *Technology Education in the 21st Century*, 111–118.
- Rosana, D., Setyaningsih, W., & Setyowati, D. (2021). STEM-based science learning to develop students' scientific skills. *Journal of Physics: Conference Series*, 1836(1), Article 012052.
- Rosidin, U., Suyatna, A., & Abdurrahman. (2019). A STEM-based learning model to improve students' scientific literacy. *Journal of Physics: Conference Series*, 1155(1), Article 012042.
- Rusydiyah, E. F., Purwati, E., & Prasetyawati, N. (2021). STEM education implementation: Teachers' perspective and challenges. *Journal of Physics: Conference Series*, 1899(1), Article 012010.
- Sagala, Y. D., Suyatna, A., & Abdurrahman. (2019). The effectiveness of STEM learning model to improve students' critical thinking skills. *Journal of Physics: Conference Series*, 1155(1), Article 012043.
- Samsudin, A., Suhandi, A., Rusdiana, D., & Kaniawati, I. (2020). STEM project-based learning to improve students' physics learning outcomes and self-efficacy. *Journal of Physics: Conference Series*, 1521(2), Article 022033.
- Setyaningsih, W., Rosana, D., & Istiyono, E. (2021). STEM learning approach to improve students' science process skills. *Jurnal Pendidikan IPA Indonesia*, 10(3), 389–398.
- Sofia, N., Permanasari, A., & Sopandi, W. (2020). STEM-based learning development to improve students' scientific literacy. *Journal of Physics: Conference Series*, 1521(4), Article 042053.
- Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, 2(1), 28–34.
- Suprpto, N. (2016). Students' attitudes towards STEM education: A preliminary study. *Journal of Physics: Conference Series*, 755(1), Article 011001.
- Sumarni, W., Wijayati, N., & Supanti, S. (2021). The effect of STEM-based learning on students' scientific literacy and creativity. *Jurnal Pendidikan IPA Indonesia*, 10(2), 230–240.
- Suratno, S., Wahono, B., Chang, C. Y., Retnowati, A., & Yushardi, Y. (2020). Exploring students' STEM learning through project-based activities. *Journal of Physics: Conference Series*, 1563(1), Article 012025.
- Susilo, H., Corebima, A. D., & Mahanal, S. (2019). STEM engineering design process in science learning to develop problem-solving skills. *Journal of Physics: Conference Series*, 1227(1), Article 012031.
- Syadiah, A. N., & Hamdu, G. (2020). STEM-based learning implementation in elementary science education. *Journal of Physics: Conference Series*, 1521(3), Article 032067.
- Syukri, M., Halim, L., & Meerah, T. S. M. (2021). STEM education implementation and its impact on students' learning outcomes. *Jurnal Pendidikan IPA Indonesia*, 10(4), 510–520.
- Thaha, H., Prabowo, C., & Rahman, A. (2021). STEM learning approach in improving students' science competencies. *Journal of Physics: Conference Series*, 1806(1), Article 012046.
- Vithanage, A., & Nakashima, H. (2025). STEM education and 21st-century skills development: Future directions. *[Journal information incomplete in manuscript]*.
- Wahono, B., & Chang, C. Y. (2019). Assessing teacher's attitude, knowledge, and application (AKA) on STEM: An effort to foster the sustainable development of STEM education. *Sustainability*, 11(4), 950.
- Wahyu, Y., Edu, A. L., & Nardi, M. (2020). Problem-based learning assisted by STEM approach to improve students' science process skills. *Jurnal Pendidikan IPA Indonesia*, 9(2), 192–201.
- Wardani, S., Yulianto, A., & Sudarmin. (2021). STEM-integrated project-based learning model and scientific literacy of prospective elementary teachers. *Jurnal Pendidikan IPA Indonesia*, 10(3), 366–375.
- Yakob, N., Yunus, M. M., & Hashim, H. (2021). STEM education implementation in science learning: A review. *Journal of Physics: Conference Series*, 1836(1), Article 012056.
- Yang, X. (2023). Exploring STEAM education and students' 21st-century competencies. *[Journal information incomplete in manuscript]*.
- Zainil, M., Kenedi, A. K., & Hendri, S. (2023). STEM and STEAM education research trends in Indonesia: A systematic review. *Journal of Education and Learning*, 17(2), 225–234.