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RESEARCH ARTICLE

Fostering Sustainability and Resiliency Skills through STEM Education Technology: A Scoping Review

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ABSTRACT

This research aims to scoping review of STEM education as meta-discipline fostering sustainability and resiliency from Japan and Indonesia publications. A total of 1112 publications collected from five electronic databases, namely Scopus, ERIC, Dimension, JS-STAGE, and SINTA. The research conducted a scoping review of STEM education technology based on STEM as a meta-discipline used to support sustainability and resiliency key framework. The scoping review was assisted by the Covidence and VOSviewer applications. The results indicate that STEM education technology potentially fosters sustainability and resiliency through system thinking (72 publications), metacognition (30 publications), scenarios thinking (49 publications) and literacy (25 publications). Moreover, this review is to introduce operationalization of STEM education role for society framework, especially to resolve socio-scientific issues (SSI's). Therefore, researchers, educators, and policy maker should be considered sustainability and resiliency as the goals for futurize STEM education.

INTRODUCTION

The importance of Science, Technology, Engineering, Mathematics (STEM) education began around 30 years ago, growing, and developing exponentially since the 1990s (Mohr-Schroeder et al., 2015). Hasanah (2020) identified four key definitions of STEM that are STEM as discipline, STEM as instruction, STEM as field, and STEM as career within the scope of STEM at the School, University, and Job levels (Hasanah, 2020). Recently, STEM education has evolved into a meta-discipline (Kennedy & Odell, 2023). STEM education and research are increasingly recognized globally as fundamental to national development and productivity, economic competitiveness and societal well-being (Freeman et al., 2019). The global urgency to improve STEM education may be driven by environmental and social impacts in the 21st century that in turn endanger global security and economic stability, known as Socio-scientific issues (SSIs). Government of both developing and developed worlds have attracted citizens through scholarships and other incentives towards STEM education owing to its endless, potentials, possibilities and the need for sustainability (Bureau, 2022). These investments are justifiable owing to the need to sustain leadership in technology, economy and security (Badmus et al., 2024).

Although various efforts have been built, the results still show intrinsic, institutional, and extrinsic obstacles (Hasanah & Tsutaoka, 2019). Freeman et al (2019) identify visible trends and commonalities regarding government STEM policies and structural responses, and student participation. STEM education not adequately preparing graduates for college, careers, and life (Kaufman, 2019). Besides that, COVID-19 pandemic confirms that education has not been able to prepare students to survive with volatility, uncertainty, complexity and ambiguity (VUCA) (Susilayati et al., 2024; Tan, 2023). The complexity of these global factors not only helps students achieve high scores on math and science assessments (Kelley & Knowles, 2016). Badmus et al (2024) identify opportunity and access for sustainability of undergraduates. Students need resiliency and sustainability to face VUCA (Spellman, 2015; Susilayati et al., 2024). Meanwhile, resiliency in science education is in line with scientific literacy to sustainability literacy (Colucci-Gray et al., 2006). Futurize STEM education, the ability to take real action and prepare for the future are important aspects of sustainability (Branchetti et al., 2018). Besides that, the increasing digital technology and global connectedness have evolved students and employees' skills need for society (Kaufman, 2019). This research aims to provides a comprehensive scoping review of STEM education technology fosters resiliency and sustainability.

Conceptual and theoretical framework

This research using opportunity to learn (OTL) concept (Elliott & Bartlett, 2016; Jam et al., 2017) and the sociocultural theory of Lev Vygotsky inserted to STEM as meta-discipline framework (Kennedy & Odell, 2023; Isa et al., 2024) as shown in Figure 1. The STEM technology supports OTL in a sociocultural context will form resiliency and sustainability agency as follows. Scientist and Mathematician generate the scientific and mathematical knowledge are used for identify socio-scientific issues (SSIs). SSIs are complex, ill-defined societal issues that have a basis in sciences (Ke et al., 2021). SSI-based instruction require the science dimension and the social ramifications to develop solutions around the issues (Nida et al., 2021). The two SSIs that have the most influence on students' lives is related to VUCA (Tan, 2023) and SDGs (Colucci-Gray et al., 2006). VUCA can be fought with vision, understanding, clarity and agility as resiliency (Cruz, 2021; Susilayati & Hardyanto, 2024). Sustainable development goals (SDGs) in education related to human development for sustainability (Kushnir & Nunes, 2022). Grey *et al* (2005) explain literacy skill relate to sustainability (Colucci-Gray et al., 2006).

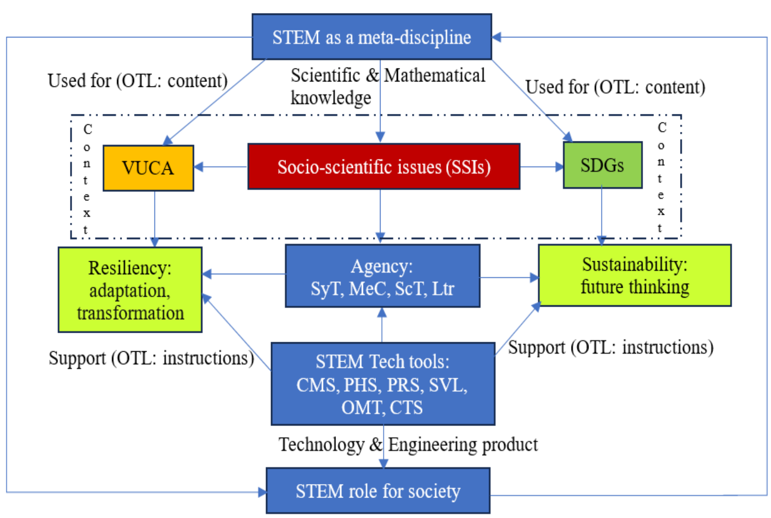

Figure 1. The STEM education technology fosters sustainability and resiliency framework

Therefore, the SSIs solution can be approached with STEM (as a meta-discipline) agencies including system thinking (SyT), metacognition (MeC), scenario thinking (ScT), and literacy (Ltr). STEM education technology tool support these agencies (Hurt et al., 2023). In STEM as a meta-discipline, technologist and engineer design and provide technology and engineering product (Kennedy & Odell, 2023). Technology and engineering product support Scientist and Mathematician to train resiliency and sustainability agencies (Kennedy & Odell, 2023). Felder (2016) categorized STEM instructional technology tools into five types, namely Course management system (CMS)/ Presentation hardware and software (PHS/ Personal response systems (PRS)/ Simulation, virtual laboratories (SVL)/ Interactive multimedia tutorials (IMT)/ Communication tools (CTS) (Felder & Brent, 2016). Overall, this conceptual operationalization framework of STEM as a meta-disciplinary plays a role in society to fosters sustainability and resiliency. For piloting, researchers used Japan and Indonesia publication as the context of developed and developing country based on PISA score.

METHODOLOGY

The researchers chose to conduct a scoping review of STEM education technology fosters resiliency and sustainability to (1) identify key characteristics STEM instructional technology tools support sustainability and resiliency agency and (2) identify and analyse STEM research gaps fosters sustainability and resiliency (Munn et al., 2018). This study approach to scoping review was systematic and shared many characteristics of systematics literature reviews (Munn et al., 2018). This scoping review using five-stage framework (Arksey & O'Malley, 2005) and the guidance proposed by Levac *et al.* (2010) and Peters et al. (Peters et al., 2020). The five-stage used in this study are (1) stating research question; (2) identifying relevant studies; (3) selecting studies; (4) charting the data; and (5) collating, summarising, and reporting results.

Stating research questions (RQs)

This research was conducted to introduce and scoping review the STEM education technology fosters sustainability and resiliency. Specifically, the purpose of this study's is to answer the following research questions (RQs):

- RQ1. What are the STEM education technology trends?
- RQ2. What are the technology link strength of STEM education technology?
- RQ3. What STEM education technology and skills foster sustainability and resiliency?

Identifying relevant studies

The researchers determine search terms and search logic to define important elements of the literature object to be studied according to the research objectives. Search term were developed using the PCC (P – Population or participants; C – Concept; and C – Context) framework, derived from the research question (Munn et al., 2018). The PCC framework using as a guide to develop clear, meaningful objective and eligibility criteria (Pollock et al., 2023). In this scoping review, P – Population was STEM education, C – Concept was resiliency and sustainability, and C – Context was Japan and Indonesia. Our search terms consisted of three main components, namely: STEM, Japan, and Indonesia, including synonyms to capture all relevant titles. Synonymous keywords are combined, while components are combined using Boolean AND to obtain more focused and productive search results (Laher & Hassem, 2020). The search terms used to include variants and synonyms are shown in Table 1.

Table 1. Key search terms

Boolean operator	PCC elements	Search terms
AND, OR	P – STEM education	STEM OR STEAM AND educat* OR learn*
OR	C – resiliency and sustainability	Resilien* OR sustainab*

Boolean operator	PCC elements	Search terms
OR	C – Japan and Indonesia	Japan OR Indonesia

The material reviewed comes from five electronic databases, namely Scopus, ERIC, Dimension, J-stage and Sinta. Scopus is an indexation service and database provider or journal data center under the auspices of Elsevier. Meanwhile, literature searches on the Scopus database are carried out with the help of Publish or Perish (PoP) software which can retrieve and analyze academic citations (Saputra et al., 2023) (https://harzing.com/resources/publish-or-perish). ERIC is widely recognized as the largest full-text database of education-related literature (https://eric.ed.gov/). Dimension is the world's largest linked research database (https://app.dimensions.ai/discover/publication). J-STAGE is a platform for scholarly publications in Japan (https://www.jstage.jst.go.jp/search/global/_search/-char/en. It is developed and managed by the Japan Science and Technology Agency. SINTA (Science and Technology Index), delivering access to citations and expertise in Indonesia sponsored by Indonesian Ministry of Education, Culture, Research and Technology (https://sinta.kemdikbud.go.id/). The combination of these five databases allows researchers to find comprehensive papers related to this research topic.

The inclusion and exclusion criteria in selecting full-text publications for scoping review based on Table 2. Selected publications had to focus STEM education topics or its synonym related to technology, resiliency and sustainability agencies in Japan/Indonesia. Other criteria included full-text empirical research in reviewed journals, published between 2014 to 2023, and written in English.

Table 2. Criteria in selecting full-text publication

Criteria	Included	Excluded
Population	Focused on STEM education topics or its synonym	Not focused STEM education topics or its synonym
Concept	Related to technology, resiliency and sustainability agencies	Not related to technology, resiliency and sustainability agencies
Context	Focuses on STEM education in Japan/Indonesia	Other country
Publication type	Full-text empirical research in peer-reviewed journals	Not empirical research: editorials, reviews, books and book chapters, conference proceedings, theses and dissertation, another document
Publication year	Published between 2014 to 2023	Published before 2014 or after 2023
Language	English	Other languages

Selection studies

Researcher selected publication studies by the multiple step search and screening process. The selection process based on the PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analysis extension for Scoping Reviews) (Tricco et al., 2018). Screening, eligibility, and inclusion were used Covidence application. Covidence is the world's number 1 software for managing and simplifying online literature reviews which can be accessed via https://app.covidence.org/. The third author imported 1112 references records from Mendeley to Covidence. Covidence helps writers check duplicate references so writers can remove them easily. A total of 9 record duplicate removed. Next, the author screened 1103 the titles and abstracts, then removed 690 irrelevant papers as shown in Figure 2. The third researcher then input the full text of the relevant articles for feasibility assessment. A total of 413 full-texts were assessed for quality to reduce bias in research results.

Inclusion criteria refers to Laher & Hassem (2020) as shown in Table 2 (Laher & Hassem, 2020). Technically, the second and third authors carried out screening independently. Two other authors resolved if there were differences in results between the second and third authors, so that the four authors discussed to determine full text inclusion.

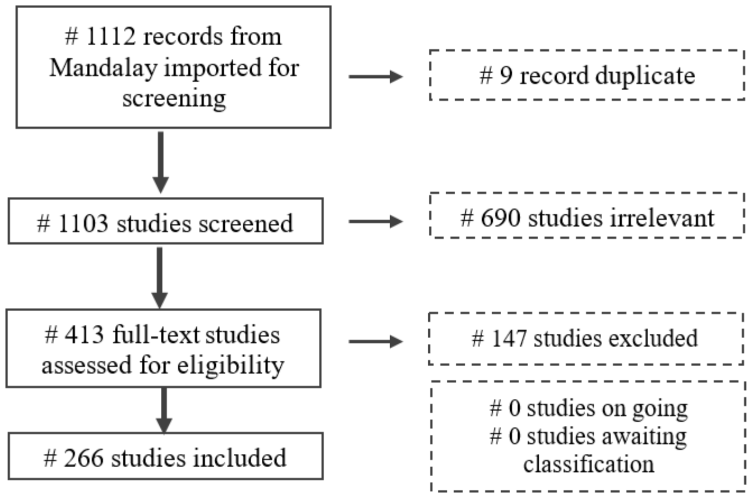

Figure 2. The PRISMA-ScR flowchart

Charting data

A total of 266 eligible full-texts were included for data extraction and synthesis. Full text extraction is classified based on some special system coding tags as in Table 3. Full text extraction is carried out in a divided manner: the first two authors carry out extraction for the first half of the number of articles, and the next two authors screen the other half. The final author reviews screening results from the first four authors. If there are disagreements, the final decision is made through discussion with all authors. After reaching a joint agreement between the five authors, export data extraction was then carried out to make synthesis. For charting data, researchers used three coding as shown in Table 3.

Table 3. Special system coding tags for data extraction

Coding	Content
STEM major disciplinary	Science (S)/ Technology (T)/ Engineering (E)/ Mathematics (M)/ Art (A)/ STEM/ STEAM/ Other (O)
Instructional technology tools (Felder & Brent, 2016)	Course management system (CMS)/ Presentation hardware and software (PHS/ Personal response systems (PRS)/ Simulation, virtual laboratories (SVL)/ Interactive multimedia tutorials (IMT)/ Communication tools (CTS)/ Other (O)
Sustainability and resiliency agencies (Colucci-Gray et al., 2006; Spellman, 2015)	System thinking (SyT)/ Metacognition (MeC)/ scenarios thinking (ScT)/ Literacy (Ltr)

The data extraction form was designed to collect data from primary studies to answer research questions (RQs) based on 267 full-texts included. Synthesis is carried out by mapping data extraction from Covidence and visual output from VOSviewer software (Hiererra et al., 2023; Mustapha et al., 2023., Nugraha et al., 2023; Van Eck & Waltman, 2023).

Coding of STEM major disciplinary

The included publications coded based on STEM major disciplinary. Researchers analysed the publication content for coded into one of seven the most appropriate STEM major disciplinary coding. The seven coding are 1) Science (S), 2) Technology (T), 3) Engineering (E), 4) Mathematics (M), 5) Art (A), 6) Science, Technology, Engineering, and Mathematics (STEM), and 7) Science, Technology, Engineering, Art, and Mathematics (STEAM).

Coding of STEM instructional technology tools

There are six coding for STEM instructional technology tools. The six coding are 1) Hardware and software (PHS, 2) Personal response systems (PRS), 3) Simulation, virtual laboratories (SVL), 4) Interactive multimedia tutorials (IMT), 5) Communication tools (CTS), and 6) Other (O). These five-coding adopted from (Felder & Brent, 2016). Researchers analysed the publication content for coded into one of six the most appropriate STEM instructional technology tools coding.

Coding of sustainability and resiliency agencies

Researchers using four-coding of sustainability and resiliency agencies (Colucci-Gray et al., 2006; Spellman, 2015). The four-coding are 1) System thinking (SyT), 2) Metacognition (MeC), 3) scenarios thinking (ScT), and 4) Literacy (Ltr). Researchers analysed the publication content for coded into one of four the most appropriate STEM major disciplinary coding.

Collating, summarizing, and reporting findings

Researchers conducted analysis by descriptive statistical (i.e frequency distribution, percentage) to answer RQ1; to answer RQ2 and RQ3 related codes were grouped into thematic categories as described in the previous section. Studies coded within the same category were revisited, and related information was collated, read, and summarized to develop thematic categories. Details from publications exemplifying particular thematic categories, or divergences, were noted. Checks were made within and across these categories, and narrative descriptions were combined to report findings with discussions among the authors.

Limitations

This scoping review has several limitations using methodological approach that should be considered. First, authors recognize that there are pros and cons for any database used; we might have missed important studies that are not indexed by SCOPUS, ERIC, Dimension, JS-STAGE, and SINTA; and/or published in language other English. Second, researchers focus on sustainability and resiliency agencies based on Spellman (2015) and Colucci-Gray et al. (2006), although there may still be other important agencies. Finally, the choice of publication context in Japan representing developed countries and Indonesia representing developing countries is also a limitation of this study. However, this study has been based on various underlying scientific considerations.

RESULTS AND DISCUSSION

STEM education technology trends (RQ1)

Trends in STEM Education publications in the last ten years (2014-2023) are presented based on trends in the number of publications on Figure 3, and STEM link category trends on Figure 4.

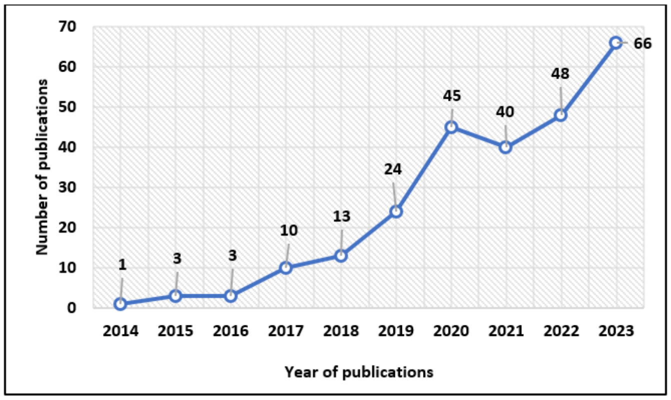

Figure 3. Trends of STEM publication numbers

Based on Figure 3, the number of STEM education publications tends to increase over the last ten years (2014-2023). STEM education is the top publication number in 2023. These results indicate that STEM is still a publication trend in the following years, including in 2024.

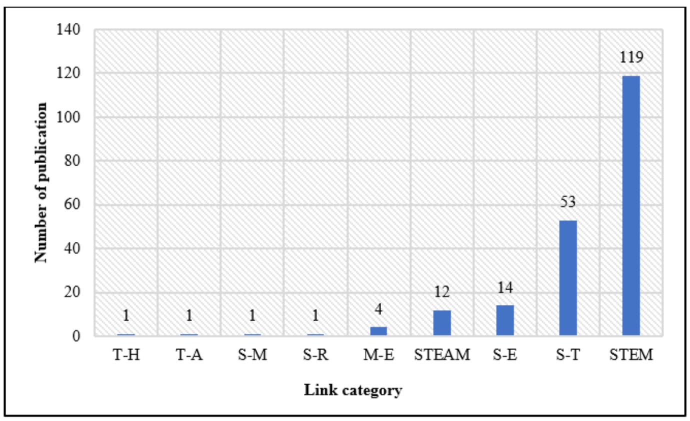

Figure 4. Trends publications of STEM link category

Link integration category:

STEM: Science-Technology-Engineering-Mathematics

S-T: Science-Technology

S-E: Science-Engineering

STEAM: Science-Technology-Engineering-Art-Mathematics

M-E: Mathematics-Engineering

S-R: Science-Religion

S-M: Science-Mathematics

T-A: Technology-Art

T-H: Technology-Humanity

Based on data extraction analysis from Covidence as shown on Figure 3, and Figure 4, STEM is the current trends of publications. This result is in line with network visualization in VOSviewer as shown on Figure 5.

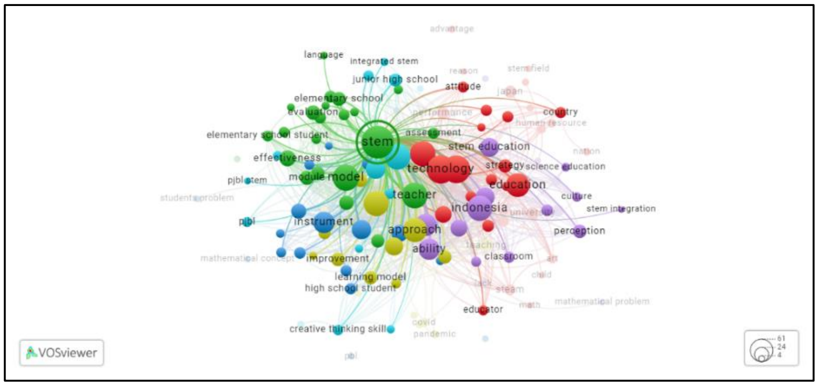

Figure 5. Trends of STEM link with VOSviewer

Based on Figure 5, STEM shows the largest size with the most networks with 123 links, 1372 link strength, and 129 occurrences. Based on this research, STEM integration provides the greatest opportunity to foster sustainability and resiliency. Researchers can utilize these themes according to their respective gaps and needs. For example, researchers can use learning models to obtain instructional impacts such as STEM-inquiry-resiliency or STEM-inquiry-sustainability. S-T link integration provides opportunity to foster sustainability and resiliency. Researchers can utilize these themes according to their respective gaps and needs. For example, researchers can use e-scaffolding to obtain instructional impacts such as ESEL-resiliency or ESEL-sustainability. Researchers can also use S-E link integration to foster sustainability and resiliency. Researchers can utilize these themes according to their respective gaps and needs. For example, researchers use EDP become EDP-resiliency or EDP-sustainability. STEAM link integration fosters sustainability and resiliency too. Thus, researchers can utilize art that is rarely featured in STEM. For example, STEAM-resiliency or STEAM-sustainability.

Link strength of STEM Education technology (RQ2)

Technology in STEM education publications was extracted based on Instructional technology tools according to Felder & Brent (2016) including six instructional technology tools. The results show that the top instructional technology tools are simulation, virtual laboratories (SVL) as shown on Figure 6.

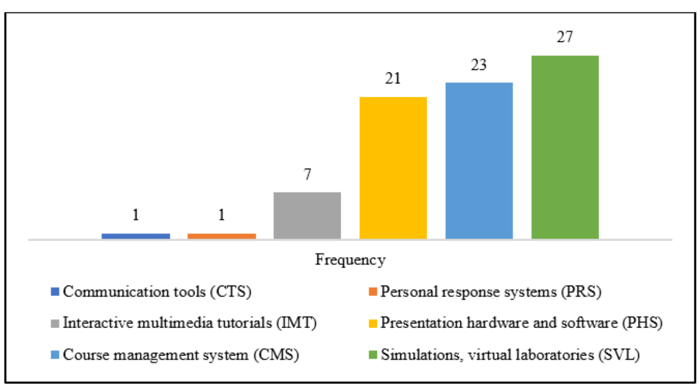

Figure 6. STEM instructional technology tools category

Apart from that, Figure 6 also shows that course management systems (CMS) and presentation hardware and software (PHS) are respectively the second and third most frequently used instructional technology tools. However, interactive multimedia tutorials (IMT), personal response systems (PRS) and communication tools (CTS) are rarely reported in STEM education publications.

Therefore, these last three instructional technology tools are an opportunity to complement publications in STEM education. Technology is the main mediator in STEM integration as shown on Figure 7.

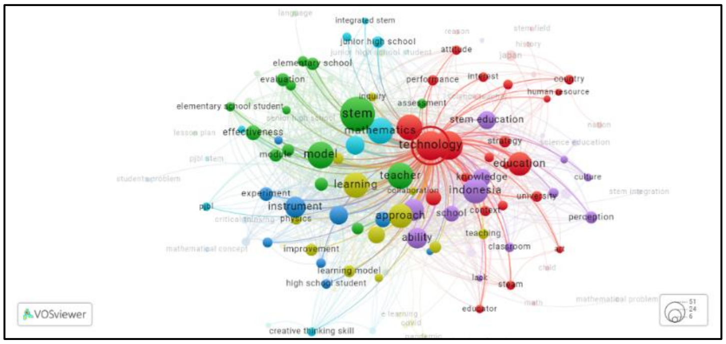

Figure 7. Network visualization of Technology publications

Based on Figure 7, technology shows the second largest visualization after STEM with 127 links, 1202 link strength, and 96 occurrences. Apart from that, STEM-technology is the top link strength (63 points), followed by STEM-science (60 points), STEM-mathematics (58 points), and STEM-engineering (55 points). Meanwhile, the link strength of technology-science is 76 points, technology-engineering is 69 points, technology-mathematics is 65 points, engineering-science is 70 points, mathematics-science is 62 points, mathematics-engineering is 65 points. Then, the technology trends in STEM education are discussed based on the instructional technology tools categories as follows.

Simulation, virtual laboratories (SVL)

The publication trends on Simulation, virtual laboratories (SVL) category including hydraulic robotics arm (Herlanti et al., 2019), game design for mobile app-based IoT (H. Lestari & Rahmawati, 2020), AI-STEM based such as game, fuzzy logic, artificial neural network, robotics (J. M. Sari & Purwanta, 2021), STEM-IoT learning media (Hamid et al., 2022), robotics project (Choirunnisa et al., 2023), hybrid laboratory of a simple spectrophotometer with STEM project-based learning (Shidiq et al., 2022), STEM-based Vlab (R. P. Sari et al., 2020), PhET simulation (Khaeruddin & Bancong, 2022; Yunzal, Jr. & Casinillo, 2020), virtual lab (Syukri et al., 2022), programming and computational thinking (Quyen et al., 2023), augmented reality (Pambudi et al., 2022), and mobile net-based transfer learning (Deviana Sely Wita & Subekti, 2023). The use of simulation and virtual laboratories have the potential to train resiliency. Robotics, game design, and simulation on Vlab or internet using can train algorithms and pattern recognition in computational thinking. This ability supports students to transform, an important part of resilience thinking (Folke et al., 2010). Besides that, the project trains students to create real work which is an important part of sustainability (Ramísio et al., 2019). Therefore, simulation & virtual laboratory as the technology and engineering product support resiliency and sustainability agencies.

Course management systems (CMS)

The publication trends on Course management systems (CMS) category including blended learning (Ardianti et al., 2020; Haryadi et al., 2021), campus e-learning (Sumin et al., 2021), cooperative problem-based learning (CPBL) (Towip et al., 2022), e-scaffolding enhance learning (ESEL) (Sarah et al., 2022), hybrid learning (Hayati et al., 2022), IBL-STEMWeb (Batlolona & Jamaludin, 2022), mobile learning application (Rachmadtullah et al., 2023), Moodle e-learning (Restanti et al., 2023), physics mobile learning (Asmiliyah et al., 2021), STEM physics interactive multimedia (Husniyah & Ramli, 2023), STEM project mobile (Siregar et al., 2023), STEM-based digital classroom (Zainil et al., 2023), STEM-based e-learning (Wiyono et al., 2022), STEM-based natural science online learning (Wardani et al., 2021), STEM-PBL approach online chemistry learning (Arisa & Sitinjak, 2022), STEM-TPACK learning website (Chai et al., 2020). Course management systems such as Moodle, digital and mobile learning are the technology and engineering product too. The use of course management systems have the potential to train resiliency on internet using. To access course management system needs algorithms and technology literacy. Algorithm supports students to transform, an important part of resilience thinking (Folke et al., 2010). Besides that, using CMS supported technology literacy, an important part of sustainability (Colucci-Gray et al., 2006). Therefore, course management systems as the technology and engineering product support resiliency and sustainability agencies.

Presentation hardware and software (PHS)

The publication trends on Presentation hardware and software (PHS) category including STEM project-based virtual learning module (Yennita et al., 2022), STEAM project-based on static fluids (Atika et al., 2023) and elasticity (Subiki et al., 2023), BOTIPOSTEM e-book (I. M. Sukma et al., 2023), PBL-STEM e-module (Adhelacahya et al., 2023), human excretory STEM e-module (Rungkat et al., 2023), interactive book augmented reality (IBAR) (Wibowo, 2021), e-learning module (Halim et al., 2020; D. A. Lestari et al., 2023; M. Sukma & Halim, 2022), video (Ramadini & Muttaqiin, 2023), STEM-SDGs e-module (Aswirna, Kiswanda, et al., 2022), Kodular and flipbook e-module (Yunianta et al., 2023), free range chicken egg productivity e-module (W et al., 2021), STEM-PBL e-module (Phandini et al., 2023), reaction rate module on google classroom (Afadil et al., 2023). Presentation hardware and software such as e-module, e-book, and video are the technology and engineering product too, contain scientific and mathematical knowledge. The use of presentation hardware and software have the potential to train resiliency on internet using. To access presentation hardware and software needs algorithms and technology literacy. Algorithm supports students to transform, an important part of resilience thinking (Folke et al., 2010). Besides that, using PHS supported technology literacy, an important part of sustainability (Colucci-Gray et al., 2006). Therefore, presentation hardware and software as the technology and engineering product support resiliency and sustainability agencies.

Interactive multimedia tutorial (IMT)

The publication trends on Interactive multimedia tutorial (IMT) category including SPLDV calc application (Hamdu et al., 2020), inquiry e-worksheet on google classroom (Rabbani et al., 2024), Quest program (Reffiane, 2021), STEM-PBL e-worksheet (Rahayu et al., 2023), space figure STEM-based discovery learning worksheet (Astryani et al., 2022). Interactive multimedia tutorial such as e-worksheet is the technology and engineering product too. Interactive multimedia tutorial provides two-way feedback between teacher and learner. Learner needs scientific and mathematical knowledge to complete worksheet. Besides that, the learner needs algorithm and technology literacy to access e-worksheet. These algorithm supports students to transform, an important part of resilience thinking (Folke et al., 2010). Using IMT trains technology literacy, an important part of sustainability (Colucci-Gray et al., 2006). Therefore, interactive multimedia tutorial as the technology and engineering product support resiliency and sustainability agencies.

Personal response system (PRS) & Communication tools (CTS)

Personal response system (PRS) RE-STEM android application (Subali et al., 2023), and communication tools (CTS) Instagram-based media and chemistry practicum video project (Anggreani et al., 2023). This study only finds out one type personal response system and communication tools in STEM education technology, namely android application and Instagram. These two technology and engineering product needs technology literacy. Using PRS and CTS also trains technology literacy, an important part of sustainability (Colucci-Gray et al., 2006). Therefore, personal response system and communication tools as the technology and engineering product support sustainability agencies.

STEM Education technology fosters sustainability and resiliency agency (RQ3)

Based on Figure 1, STEM education technology fosters resilience with systems thinking, metacognition, and scenarios thinking (Spellman, 2015) and sustainability with literacy (Colucci-

Gray et al., 2006). There are so many STEM education publications foster resiliency and sustainability as shown in Figure 8. Then, the STEM education technology is discussed based on the resiliency and sustainability agency categories as follows.

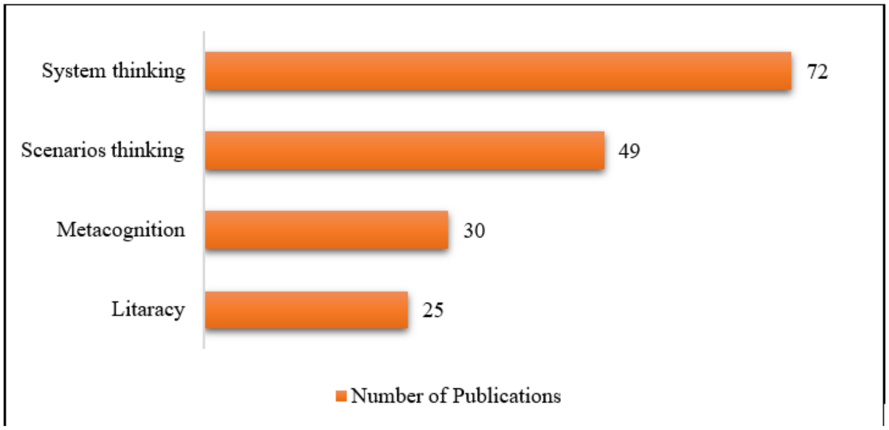

Figure 8. STEM education technology foster sustainability and resiliency skills

System thinking

System thinking agency is the top STEM education publications foster resiliency and sustainability as shown in Figure 8. There are 12 skills developed with STEM education technology as shown in Table 4.

Table 4. STEM education technology fosters system thinking

No.	Skills	STEM Education technology					
		SVL	CMS	PHS	IMT	PRS	CTS
1.	Complex matter for design project		√				
2.	Concept mastery and understanding		√	√			
3.	Creative learning	√					
4.	HOTS skill		√	√			
5.	Learning outcome	√		√	√		
6.	Problem solving		√	√	√		
7.	Reasoning ability		√				
8.	Reduce misconception			√			
9.	Science and scientific concept	√					
10.	Scientific work	√					
11.	Thinking skill		√				
12.	Mastery knowledge and limited time		√				

Students' skills related to system thinking agency including complex matter for design project (Chai et al., 2020), concept mastery and understanding (Atika et al., 2023; Sarah et al., 2022), creative learning (J. M. Sari & Purwanta, 2021), creative thinking (Afadil et al., 2023; Anggreani et al., 2023; D. A. Lestari et al., 2023), HOTS skill (Haryadi et al., 2021; Restanti et al., 2023; Yennita et al., 2022), learning outcome (Astryani et al., 2022; Hamid et al., 2022; Subiki et al., 2023), problem solving (Batlolona & Jamaludin, 2022; T. Lestari et al., 2023; Reffiane et al., 2021), reasoning ability (Siregar et al., 2023), reduce misconception (Halim et al., 2020; M. Sukma & Halim, 2022), science and scientific concept (Syukri et al., 2022), scientific work (R. P. Sari et al., 2020), thinking skill (Irwandi et al., 2020).

Based on Table 4, there are 12 skills foster resiliency related to system thinking. These skills provide students' ability to adapt and transform. Besides students' skills, the publications also discuss teacher preparation for resiliency. The teacher preparation for resiliency including mastery knowledge and limited time (Husniyah & Ramli, 2023) needs consideration. There are eight teacher preparations to conduct STEM education for resiliency. Professional development for resiliency can be highlighted as the main preparation. This professional development can be started from indigenizing science curriculum, mastery technological, pedagogical, and content knowledge (TPACK), including time management.

Scenario thinking

Scenario thinking agency is the second rank STEM education foster resiliency and sustainability as shown in Figure 8. There are 10 skills developed with STEM education technology foster scenario thinking as shown in Table 5.

Table 5. STEM education technology fosters scenario thinking

No.	Skills	STEM Education technology					
		SVL	CMS	PHS	IMT	PRS	CTS
1.	21th century skills		√				
2.	Collaboration skill		√				
3.	Communication		√		√		
4.	Differences student			√			
5.	HOTS and 21th century skill		√				
6.	Mathematic communications			√			
7.	Motivation	√					
8.	Performance	√					
9.	Social emotional		√				
10.	STEM scenarios			√			

Scenario thinking is the second rank of STEM education publication. The publication related to scenarios thinking agency including 21th century skills (Towip et al., 2022), collaboration skill (Wiyono et al., 2022), communication (Fujita, 2021; Kadota, 2017; Rabbani et al., 2024; Rahayu et al., 2023; Wardani et al., 2021), differences student (Yunianta et al., 2023), HOTS and 21th century skill (Zainil et al., 2023), mathematic communications (Wandani et al., 2023), motivation (Rukayah et al., 2022), performance (Yunzal, Jr. & Casinillo, 2020), social emotional (Fukushima et al., 2009), and STEM scenarios (Wibowo et al., 2021).

According to Spellman (2015) scenarios thinking strategy including backward and forward timeline creation, futures wheels, and cross impact matrices. Backward and forward timeline strategy in this study including 21th century skills, collaboration, communication, and STEM scenario. The cross impact metrices strategy including mathematic communication. Besides that, future wheels strategy could be provided such as motivation and social emotional, including difference students for futurize STEM education (Branchetti et al., 2018; Levrini et al., 2021).

Metacognition

Metacognition agency is the third rank STEM education technology foster resiliency and sustainability as shown in Figure 8. There are 5 skills can be developed with STEM education technology as shown in Table 6.

Table 6. STEM education technology fosters metacognition

No.	Skills	STEM Education technology					
		SVL	CMS	PHS	IMT	PRS	CTS
1.	Cognitive		√				
2.	Critical thinking	√	√	√	√		

3.	Critical and creative thinking			√			
4.	Solve complex issues		√				
5.	Spatial ability and reasoning	√					

The STEM education technology fosters metacognition agency including cognitive (Hayati et al., 2022), critical thinking (Adhelacahya et al., 2023; Ardianti et al., 2020; Hamdu et al., 2020; Indra Puja Laksana et al., 2023; Khaeruddin & Bancong, 2022; Phandini et al., 2023; Ramadini & Muttaqiin, 2023; Syukri et al., 2023), critical and creative thinking (Aswirna, Samad, et al., 2022; I. M. Sukma et al., 2023), solve complex issues (Asmiliyah et al., 2021), spatial ability and reasoning (Pambudi et al., 2022). This study highlighted ability to solve complex issues as the main skill. This skill fosters resiliency agency and other skill as stated above.

Literacy

The final agency is literacy skill for sustainability. There are 4 skills can be developed with STEM education technology as shown in Table 7. The STEM education skills related to literacy for sustainability including scientific literacy and environmental friendly (Aswirna, Kiswanda, et al., 2022), digital literacy (Sumin et al., 2021), scientific literacy (Choirunnisa et al., 2023; Subali et al., 2023; Yuberti et al., 2022), visual literacy (Abdullah, 2023).

Table 7. STEM education technology fosters metacognition

No.	Skills	STEM Education technology					
		SVL	CMS	PHS	IMT	PRS	CTS
1.	Scientific literacy and environmental friendly			√			
2.	Digital literacy		√				
3.	Scientific literacy	√				√	
4.	Visual literacy				√		

Based on Table 7, there are 4 skills foster literacy for sustainability. This study highlighted STEM literacy as the main skill that covers other skills.

DISCUSSION

This study scoping 31 skills from STEM education technology fosters resiliency and sustainability into four agencies, including system thinking, scenario thinking, metacognition, and literacy. Based on conceptual and theoretical framework in Figure 1, the STEM education technology supported students' opportunity to learn with Course management system (CMS)/ Presentation hardware and software (PHS/ Personal response systems (PRS)/ Simulation, virtual laboratories (SVL)/ Interactive multimedia tutorials (IMT)/ Communication tools (CTS) (Elliott & Bartlett, 2016; Felder & Brent, 2016). These six types of STEM education technology as the tools to support instructional quality more interactive and effective. Based on the sociocultural theory of Lev Vigotsky, these tools act as environmental contribution to individual development of learner. Therefore, the 31 skills as cognitive functioning a results of interaction on human learning as social process (Badmus et al., 2024).

SSIs in the context of VUCA and SDGs as the real world need to be solved. The SSIs solution can be approached with STEM (as a meta-discipline) agencies including system thinking (SyT), metacognition (MeC), scenario thinking (ScT), and literacy (Ltr). STEM education technology tool support these agencies (Hurt et al., 2023). This study operationalize STEM as a meta-discipline, technologist and engineer design and provide technology and engineering product (Kennedy & Odell, 2023). Technology and engineering product support Scientist and Mathematician to train resiliency and sustainability agencies (Kennedy & Odell, 2023).

CONCLUSION

The technology integration in STEM education as a meta-discipline determined by trends, link strength, scoping and further research fostering sustainability and resiliency. Based on the data, analysis and discussion above, it can be concluded that STEM education shows the top publication number in 2023 indicate its current trends. Science discipline and STEM link category are also the current trends with the most weight visualization, most strength, and most occurrences. Technology is the main mediator in STEM integration. The top three instructional technology tools are simulation, virtual laboratories (SVL), course management systems (CMS), and presentation hardware and software (PHS) can be adopted for effectively STEM education. However, the lowest three instructional technology tools are interactive multimedia tutorials (IMT), personal response systems (PRS) and communication tools (CTS) need to be followed up. STEM education fosters sustainability and resiliency in three categories including system thinking, metacognition, scenarios thinking, and literacy. For futurize STEM education, researchers, educators, and policy maker should be considered sustainability and resiliency as the goals. Thus, students can compass and overcome uncertainty and unexpected pandemics may happen in their future life.

REFERENCES

Abdullah, K. H. (2023). Divulging two decades of multimedia applications in biology education. *Jurnal Inovasi Pendidikan IPA*, *9*(2), 177–191. https://doi.org/10.21831/jipi.v9i2.57361

Abdurrahman. (2019). Developing STEM Learning Makerspace for Fostering Student's 21st Century Skills in the Fourth Industrial Revolution Era. *Journal of Physics: Conference Series*, *1155*(1). https://doi.org/10.1088/1742-6596/1155/1/012002

Abdurrahman, Ariyani, F., Achmad, A., & Nurulsari, N. (2019). Designing an Inquiry-based STEM Learning strategy as a Powerful Alternative Solution to Enhance Students' 21st-century Skills: A Preliminary Research. *Journal of Physics: Conference Series*, *1155*(1). https://doi.org/10.1088/1742-6596/1155/1/012087

Adhelacahya, K., Sukarmin, S., & Sarwanto, S. (2023). The Impact of Problem-Based Learning Electronics Module Integrated with STEM on Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 4869–4878. https://doi.org/10.29303/jppipa.v9i7.3931

Afadil, Rahmawati, S., Alisa, W. N., & Mustapa, K. (2023). Using the Reaction Rate Learning Module with a STEM Approach to Student's Creative Thinking Ability. *Jurnal Pendidikan Kimia Indonesia*, *7*(1), 36–45. https://doi.org/10.23887/jpki.v7i1.55637

Alatas, F., & Yakin, N. A. (2021). The Effect of Science, Technology, Engineering, and Mathematics (STEM) Learning on Students' Problem Solving Skill. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *6*(1), 1. https://doi.org/10.26737/jipf.v6i1.1829

Anggreani, C. N., Yamtinah, S., Susilowati, E., Shidiq, A. S., & Widarti, H. R. (2023). Instagram-based Learning Media and Chemistry Practicum Video Projects to Improve Students' Creative Thinking Skills. *JPI (Jurnal Pendidikan Indonesia)*, *12*(2), 234–244. https://doi.org/10.23887/jpiundiksha.v12i2.58310

Anugrah, I. R. (2021). Students' perspectives on Batik Cirebon for high school chemistry embedded STEM learning. In *Journal of Physics: Conference Series* (Vol. 1957, Issue 1). https://doi.org/10.1088/1742-6596/1957/1/012030

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*(3), 24–32. https://doi.org/10.13189/ujer.2020.081503

Arisa, S., & Sitinjak, D. S. (2022). Implementation of the STEM-PBL Approach in Online Chemistry Learning and its Impact on Students' Critical Thinking Skills. *Jurnal Pendidikan Kimia Indonesia*, *6*(2), 88–96. https://doi.org/10.23887/jpki.v6i2.44317

Arivina, A. N., & Jailani, J. (2020). Development of trigonometry learning kit with a STEM approach to improve problem solving skills and learning achievement. *Jurnal Riset Pendidikan Matematika*, *7*(2), 178–194. https://doi.org/10.21831/jrpm.v7i2.35063

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology: Theory and Practice*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Asmiliyah, A., Khaerudin, K., & Solihatin, E. (2021). Mobile Learning with STEM Approach in Physics Learning. *Journal of Education Research and Evaluation*, *5*(4), 606. https://doi.org/10.23887/jere.v5i4.34275

Astryani, D. S., Susanta, A., Koto, I., & Susanto, E. (2022). STEM-Integrated Student Worksheets on Space Figure Using the Discovery Learning Model for Elementary School Students. *Profesi Pendidikan Dasar*, *9*(2), 191–205. https://doi.org/10.23917/ppd.v9i2.19319

Aswirna, P., Kiswanda, V., Nurhasnah, N., & Fahmi, R. (2022). Implementation of STEM E-Module with SDGs Principle to Improve Science Literacy and Environment-friendly Attitudes in Terms of Gender. *JTK (Jurnal Tadris Kimiya)*, *7*(1), 64–77. https://doi.org/10.15575/jtk.v7i1.16599

Aswirna, P., Samad, D., Devi, I. S., Fahmi, R., & Jannah, R. (2022). STEM-Based E-Module Integrated Local Wisdom of Rice Stem Fertilizers on Students' Critical and Creative Thinking. *Al-Ta Lim Journal*, *29*(1), 15–23. https://doi.org/10.15548/jt.v29i1.764

Atika, S. D., Santhalia, P. W., & Sudjito, D. N. (2023). STEAM Integrated Project Based Learning Exploration Against Understanding the Concept of Static Fluids. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5357–5364. https://doi.org/10.29303/jppipa.v9i7.2905

Azizah, Z., Ohyama, T., Zhao, X., Ohkawa, Y., & Mitsuishi, T. (2023). Measuring Motivational Pattern on Second Language Learning and its Relationships to Academic Performance: A Case Study of Blended Learning Course. *IEICE Transactions on Information and Systems*, *E106.D*(11), 1842–1853. https://doi.org/10.1587/transinf.2023EDP7052

Badmus, O. T., Jita, T., & Jita, L. C. (2024). Exploring Undergraduates' Underachievement in Science Technology Engineering and Mathematics: Opportunity and Access for Sustainability. *European Journal of STEM Education*, *9*(1), 1–11. https://doi.org/10.20897/ejsteme/14741

Batlolona, J. R., & Jamaludin, J. (2022). Physics Problem Solving Skills with IBL-STEMWeb: Students on Small Islands in Maluku. *Jurnal Penelitian Pendidikan IPA*, *8*(2), 592–598. https://doi.org/10.29303/jppipa.v8i2.1344

Batubara, I. H., Saragih, S., Syahputra, E., Armanto, D., Sari, I. P., Lubis, B. S., & Siregar, E. F. S. (2022). Mapping Research Developments on Mathematics Communication: Bibliometric Study by VosViewer. *AL-ISHLAH: Jurnal Pendidikan*, *14*(3), 2637–2648. https://doi.org/10.35445/alishlah.v14i3.925

Branchetti, L., Cutler, M., Laherto, A., Levrini, O., Palmgren, E. K., Tasquier, G., & Wilson, C. (2018). The I SEE project: An approach to futurize STEM education. *Visions for Sustainability*, *9*, 10–26. http://www.ojs.unito.it/index.php/visions/article/view/2770%0Ahttp://files/126/Branchetti et al. - 2018 - The I SEE project An approach to futurize STEM ed.pdf

Bureau, U. of L. S. (2022). *Employment in STEM Occupations*. Employment Projections. https://www.bls.gov/emp/tables/stem-employment.htm

Chai, C. S., Rahmawati, Y., & Jong, M. S.-Y. (2020). Indonesian science, mathematics, and engineering preservice teachers' experiences in stem-tpack design-based learning. *Sustainability (Switzerland)*, *12*(21), 1–14. https://doi.org/10.3390/su12219050

Choirunnisa, N. L., Suryanti, & Rahmawati, D. (2023). The Effectiveness of STEAM Learning Based on "Robotis" Projects to Improve Science Literacy of Elementary School Students. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 4836–4841. https://doi.org/10.29303/jppipa.v9i6.3524

Colucci-Gray, L., Camino, E., Barbiero, G., & Gray, D. (2006). From scientific literacy to sustainability literacy: An ecological framework for education. *Science Education*, *90*(2), 227–252. https://doi.org/10.1002/sce.20109

Cruz, J. P. (2021). Journey to the Uncertainty of the Earth: A Narrative of Teacher's Experience During COVID-19 Pandemic. *International Journal of Academic Multidisciplinary Research*, *5*(5), 135–137. https://www.researchgate.net/publication/337111157_Te

Dahiana, W. O., Herman, T., Nurlaelah, E., & Pereira, J. (2023). Student Semiotic Representation Skills in Solving Mathematics Problems. *Jurnal Didaktik Matematika*, *10*(1), 34–47. https://doi.org/10.24815/jdm.v10i1.30770

Deviana Sely Wita, & Subekti, A. (2023). Mobilenet-based Transfer Learning for Detection of Eucalyptus Pellita Diseases. *Jurnal Nasional Pendidikan Teknik Informatika (JANAPATI)*, *12*(1), 1–7. https://doi.org/10.23887/janapati.v12i1.53220

Elliott, S. N., & Bartlett, B. J. (2016). Opportunity to Learn. In *Oxford Handbook Topics in Psichology*.

Felder, R. M., & Brent, R. (2016). *Teaching and Learning STEM: A Practical Guide*. Jossey-Bass. https://doi.org/10.1119/1.5018684

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society*, *15*(4). https://doi.org/10.5751/ES-03610-150420

Freeman, B., Marginson, S., & Tytler, R. (2019). An International View of STEM Education. In *STEM Education 2.0* (pp. 350–363). Brill. https://doi.org/https://doi.org/10.1163/9789004405400_019

Fujita, T. (2021). on Online Teaching and Learning of Mathematics: What Future Research Can Be Expected By Mathematics Education Research? *Hiroshima Journal of Mathematics Education*, *14*, 37–51.

Fukushima, M., Ito, H., Kubo-Kawai, N., Sugasawara, H., Yamamoto, J., & Masataka, N. (2009). How can cognitive and learning science contribute to implementing E-learning in Japanese schools? *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, *16*(3), 377–389. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=psyc6&NEWS=N&AN=2009-24914-006

Hafni, R. N., Herman, T., Nurlaelah, E., & Mustikasari, L. (2020). The importance of science, technology, engineering, and mathematics (STEM) education to enhance students' critical thinking skill in facing the industry 4.0. *Journal of Physics: Conference Series*, *1521*(4), 0–7. https://doi.org/10.1088/1742-6596/1521/4/042040

Halim, A., Soewarno, S., Elmi, E., Zainuddin, Z., Huda, I., & Irwandi, I. (2020). The Impact of the E-Learning Module on Remediation of Misconceptions in Modern Physics Courses. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *6*(2), 203–216. https://doi.org/10.21009/1.06207

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. https://doi.org/10.23887/jpi-undiksha.v9i1.20884

Hamid, A., Syukri, M., Halim, A., & Irwansyah, I. (2022). Development of Internet of Things Based Learning Media Through STEM Investigative Science Learning Environment Approach to Improve Student Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 1985–1992. https://doi.org/10.29303/jppipa.v8i4.1634

Hanif, S., Wijaya, A. F. C., Winarno, N., & Salsabila, E. R. (2019). The use of STEM project-based learning toward students' concept mastery in learning light and optics. *Journal of Physics: Conference Series*, *1280*(3). https://doi.org/10.1088/1742-6596/1280/3/032051

Haryadi, R., Situmorang, R., & Khaerudin, K. (2021). Enhancing Students' High-Order Thinking Skills through STEM-Blended Learning on Kepler's Law During Covid-19 Outbreak. *Jurnal Penelitian Dan Pembelajaran IPA*, *7*(2), 168. https://doi.org/10.30870/jppi.v7i2.12029

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

Hasanah, U., & Tsutaoka, T. (2019). An outline of worldwide barriers in science, technology, engineering and mathematics (STEM) education. *Jurnal Pendidikan IPA Indonesia*, *8*(2), 193–200. https://doi.org/10.15294/jpii.v8i2.18350

Hayati, N., Muthmainah, & Wulandari, R. (2022). Children's Online Cognitive Learning Through Integrated Technology and Hybrid Learning. *JPUD - Jurnal Pendidikan Usia Dini*, *16*(1), 116–132. https://doi.org/10.21009/jpud.161.08

Henukh, A., Simbolon, M., Astra, I. M., & Rosdianto, H. (2021). Analysis of Students' Science Literacy Ability on Heat Concept. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *6*(2), 178. https://doi.org/10.26737/jipf.v6i2.2077

Herlanti, Y., Mardiati, Y., Rahmawati, R., Putri, A. M. K., Jamil, N., Miftahuzzakiyah, M., Sofyan, A., Zulfiani, Z., & Sugiarti, S. (2019). Finding Learning Strategy in Improving Science Literacy. *Jurnal Penelitian Dan Pembelajaran IPA*, *5*(1), 59. https://doi.org/10.30870/jppi.v5i1.4902

Hiererra, S. E., Meyliana, M., Ramadhan, A., & Purnomo, F. (2023). The Requirement Aspect for Sustainability Smart Tourism Destinations: a Systematic Literature Review and Proposed Model Analysis. *Journal of Engineering Science and Technology*, *18*(6), 2895–2914.

Hurt, T., Greenwald, E., Allan, S., Cannady, M. A., Krakowski, A., Brodsky, L., Collins, M. A., Montgomery, R., & Dorph, R. (2023). The computational thinking for science (CT-S) framework: operationalizing CT-S for K–12 science education researchers and educators. *International Journal of STEM Education*, *10*(1), 1–16. https://doi.org/10.1186/s40594-022-00391-7

Husniyah, R., & Ramli, R. (2023). Development of Physics Interactive Multimedia Based on STEM Approach Class XI SMA. *Jurnal Penelitian Pendidikan IPA*, *9*(5), 3899–3904. https://doi.org/10.29303/jppipa.v9i5.3542

Indra Puja Laksana, Evi Dwi Wahyuni, & Christian Sri Kusuma Aditya. (2023). Game Design for Mobile App-Based IoT Introduction Education in STEM Learning. *Jurnal RESTI (Rekayasa Sistem Dan Teknologi Informasi)*, *7*(3), 688–696. https://doi.org/10.29207/resti.v7i3.5007

Irwandi, I., Oktavia, R., Rajibussalim, & Halim, A. (2020). Using the ELVIS II+ platform to create "learning is fun" atmosphere with the ISLE-based STEM approach. *Journal of Physics: Conference Series*, *1470*(1). https://doi.org/10.1088/1742-6596/1470/1/012003

Irwandi, Oktavia, R., Rajibussalim, Halim, A., & Melvina. (2018). Light Emitting Diode (LED) as an essential prop component for STEM education in the 21st century: A focus for secondary school level. *Journal of Physics: Conference Series*, *1088*. https://doi.org/10.1088/1742-6596/1088/1/012060

Isnaini, M., Farwati, R., Metafisika, K., & Nasrudin, D. (2023). Cognitive of Pre-service Teachers in Designing STEM-based Learning Using CODE-PLAN Model. *Jurnal Penelitian Dan Pembelajaran IPA*, *9*(2), 271. https://doi.org/10.30870/jppi.v9i2.21557

Istiana, R., Herawati, D., Herniningtyas, F., Ichsan, I. Z., & Ali, A. (2023). STEM Learning to Improve Problem Solving Ability on the Topic of Environmental Education. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1202–1208. https://doi.org/10.29303/jppipa.v9i3.2979

Kadota, K. (2017). Development of communication robot for STEM education by using digital fabrication. In *Journal of Robotics and Mechatronics* (Vol. 29, Issue 6, pp. 944–951). https://doi.org/10.20965/jrm.2017.p0944

Kaufman, K. (2019). What Skills Do 21st Century High School Graduates Need to Have to Be Successful in College and Life? In *STEM Education 2.0* (pp. 337–349). Brill. https://doi.org/https://doi.org/10.1163/9789004405400_018

Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2021). *Developing and Using Multiple Models to Promote Scientific Literacy in the Context of Socio - Scientific Issues*. 589–607. https://doi.org/10.1007/s11191-021-00206-1

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1). https://doi.org/10.1186/s40594-016-0046-z

Kennedy, T. J., & Odell, M. R. L. (2023). STEM Education as a Meta-discipline. In B. Akpan, B. Cavas, & T. Kennedy (Eds.), *Contemporary Issues in Science and Technology Education* (pp. 37–51). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-24259-5_4

Khaeruddin, K., & Bancong, H. (2022). STEM education through PhET simulations: An effort to enhance students' critical thinking skills. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *11*(1), 35–45. https://doi.org/10.24042/jipfalbiruni.v11i1.10998

Kim, J.-Y., Chung, H., Jung, E. Y., Kim, J.-O., & Lee, T.-W. (2020). Development and Application of a Novel Engineering-Based Maker Education Course for Pre-Service Teachers. *Education Sciences*, *10*(5), 126. https://doi.org/10.3390/educsci10050126

Komarudin, U., Rustaman, N. Y., & Hasanah, L. (2017). Promoting students' conceptual understanding using STEM-based e-book. *AIP Conference Proceedings*, *1848*. https://doi.org/10.1063/1.4983976

Krisdiana, I., Setyansah, R. K., & Pratiwi, I. A. (2020). Student Worksheets With The Spldv Calc Application To Improve Creative Thinking Abilities. *JPI (Jurnal Pendidikan Indonesia)*, *9*(4), 686. https://doi.org/10.23887/jpi-undiksha.v9i4.19366

Kushnir, I., & Nunes, A. (2022). Education and the UN Development Goals Projects (MDGs and SDGs): Definitions, Links, Operationalisations. *Journal of Research in International Education*, *21*(1), 3–21. https://doi.org/10.1177/14752409221088942

Laher, S., & Hassem, T. (2020). Doing systematic reviews in Psychology. *South African Journal of Psychology*, *50*(4), 450–468. https://doi.org/10.1177/0081246320956417

Lestari, D. A., Suwarma, I. R., & Suhendi, E. (2023). Development of STEM-Based Physics Module with Self-Regulated Learning to Train Students Critical Thinking Skills. *Jurnal Penelitian Dan Pengembangan Pendidikan Fisika*, *9*(2), 197–206. https://doi.org/10.29303/jppipa.v9i6.3578

Lestari, H., & Rahmawati, I. (2020). Integrated STEM through Project Based Learning and Guided Inquiry on Scientific Literacy Abilities in Terms of Self-Efficacy Levels. *Al Ibtida: Jurnal Pendidikan Guru MI*, *7*(1), 19. https://doi.org/10.24235/al.ibtida.snj.v7i1.5883

Lestari, T., Nurhanurawati, Caswita, & Yulianti, D. (2023). Thematic Teaching Materials Using Science, Technology, Engineering and Mathematics Approaches to Improve Problems Solving Ability of Elementary School Students. *Jurnal Penelitian Dan Pengembangan Pendidikan*, *7*(1), 126–134. https://doi.org/10.23887/jppp.v7i1.60361

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: advancing the methodology. *Implementation Science*, *5*(69), 1–9. https://doi.org/10.1017/cbo9780511814563.003

Levrini, O., Tasquier, G., Barelli, E., Laherto, A., Palmgren, E., Branchetti, L., & Wilson, C. (2021). Recognition and operationalization of Future-Scaffolding Skills: Results from an empirical study of a teaching–learning module on climate change and futures thinking. *Science Education*, *105*(2), 281–308. https://doi.org/10.1002/sce.21612

Listiana, L., Abdurrahman, A., Suyatna, A., & Nuangchalerm, P. (2019). The Effect of Newtonian Dynamics STEM-Integrated Learning Strategy to Increase Scientific Literacy of Senior High School Students. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *8*(1), 43–52. https://doi.org/10.24042/jipfalbiruni.v8i1.2536

Lusyana, E., & Setyaningrum, W. (2018). van Hiele instructional package for vocational school students' spatial reasoning. *Beta: Jurnal Tadris Matematika*, *11*(1), 79–100. https://doi.org/10.20414/betajtm.v11i1.146

Mardita, M., Alim, J. A., Hermita, N., & Wijaya, T. T. (2022). The Effect of Thinking-Based STEM Learning on Students' Critical Thinking Ability. *Journal of Educational Science and Technology*, *8*(2), 150–155.

Marsari, H., & Rifma, R. (2023). The Development of STEM-Based Teaching Materials to Improve Science Literacy for Grade III Elementary School Students. *AL-ISHLAH: Jurnal Pendidikan*, *15*(2), 1297–1309. https://doi.org/10.35445/alishlah.v15i2.2809

Mayasari, D., Natsir, I., & Taufik, A. R. (2021). Analysis of Students' Mathematical Problem-Solving Ability in Term of Multiple Intelligence. *Jurnal Didaktik Matematika*, *8*(2), 250–266. https://doi.org/10.24815/jdm.v8i2.20369
Mayasari, T., Susilowati, E., & Winarno, N. (2019). Practicing integrated STEM in renewable energy projects: Solar power. *Journal of Physics: Conference Series*, *1280*(5). https://doi.org/10.1088/1742-6596/1280/5/052033
Milaturrahmah, N., Mardiyana, & Pramudya, I. (2017). Science, technology, engineering, mathematics (STEM) as mathematics learning approach in 21st century. *AIP Conference Proceedings*, *1868*(October 1983). https://doi.org/10.1063/1.4995151
Miranti, H., Abdurrahman, & Hasnunidah, N. (2020). Perspective of students' science communication in science learning: Opportunity in developing makerspace STEM learning approach. *Journal of Physics: Conference Series*, *1572*(1). https://doi.org/10.1088/1742-6596/1572/1/012049
Mohr-Schroeder, M. J., Cavalcanti, M., & Blyman, K. (2015). STEM Education: Understanding the Changing Landscape. In A. Sahin (Ed.), *A Practice-based Model of STEM Teaching* (pp. 3–14). SensePublishers. https://doi.org/10.1007/978-94-6300-019-2_1
Munn, Z., Peters, M. D. J., Stem, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology*, *18*(143), 1–7. https://doi.org/10.4324/9781315159416
Murtiyasa, B., & Wulandari, S. (2022). Problem Solving Ability According to Polya on System of Linear Equations in Two Variables Based on Student Learning Styles. *Jurnal Didaktik Matematika*, *9*(2), 261–279. https://doi.org/10.24815/jdm.v9i2.26328
Mustapha, R., Fauzi, M. A., Soon, O. T., Wei, L. H., & Yee, C. M. (2023). Employee Perception of Whistleblowing in the Workplace: A Systematic Bibliometric Review. *Pakistan Journal of Life and Social Sciences*, *22*(1), 16–32. https://doi.org/10.57239/PJLSS-2024-22.1.002
Mutakinati, L., Anwari, I., & Yoshisuke, K. (2018). Analysis of students' critical thinking skill of middle school through stem education project-based learning. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 54–65. https://doi.org/10.15294/jpii.v7i1.10495
Ngan, L. H. M., Hien, N. Van, Hoang, L. H., Hai, N. D., & Bien, N. Van. (2020). Exploring Vietnamese Students' Participation and Perceptions of Science Classroom Environment in STEM Education Context. *Jurnal Penelitian Dan Pembelajaran IPA*, *6*(1), 73. https://doi.org/10.30870/jppi.v6i1.6429
Nida, S., Mustikasari, V. R., & Eilks, I. (2021). *Indonesian Pre-Service Science Teachers ' Views on Socio-Scientific Issues- Based Science Learning*. *17*(1), 1–11.
Nugraha, R. A., Budimansyah, D., Kuswanto, K., Nugraha, D. M., Supriyono, S., Supriatna, A., & Azis, A. (2023). Augmented Reality in Education Review: Bibliometric Computational Mapping Analysis Using Vosviewer. *Journal of Engineering Science and Technology*, *18*(6), 2976–2989.
Nugroho, O. F., Permanasari, A., Firman, H., & Riandi, R. (2021). The Urgency of STEM Education in Indonesia. *Jurnal Penelitian Dan Pembelajaran IPA*, *7*(2), 260. https://doi.org/10.30870/jppi.v7i2.5979
Nuraini, N., Asri, I. H., & Fajri, N. (2023). Development of Project Based Learning with STEAM Approach Model Integrated Science Literacy in Improving Student Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1632–1640. https://doi.org/10.29303/jppipa.v9i4.2987
Omata, K., & Imai, S. (2022). An Exploratory Study on PBL Lessons Using IoT Teaching Materials in Elementary Schools. *Information and Technology in Education and Learning*, *2*(1), Trans-p009-Trans-p009. https://doi.org/10.12937/itel.2.1.trans.p009
Onsee, P., & Nuangchalerm, P. (2019). Developing Critical Thinking of Grade 10 Students through Inquiry-Based STEM Learning. *Jurnal Penelitian Dan Pembelajaran IPA*, *5*(2), 132. https://doi.org/10.30870/jppi.v5i2.5486

Pambudi, M. H., Suyitno, A., & Mastur, Z. (2022). Development of Application Based on Augmented Reality to Improve Student's Spatial Ability. *Jurnal Didaktik Matematika*, *9*(2), 314–327. https://doi.org/10.24815/jdm.v9i2.25936

Panggabean, F. T. M., Silitonga, P. M., Sutiani, A., Purba, J., & Gultom, R. (2023). Inquiry Based Learning STEM Teaching Materials to Improve Students' Thinking Skills in Stoichiometry. *JTK (Jurnal Tadris Kimiya)*, *8*(2), 157–164. https://doi.org/10.15575/jtk.v8i2.28870

Parno, Permana, G. A., Hidayat, A., & Ali, M. (2021). Improving Students Understanding on Fluid Dynamics through IBL-STEM Model with Formative Assessment. *Journal of Physics: Conference Series*, *1747*(1). https://doi.org/10.1088/1742-6596/1747/1/012008

Parno, Yuliati, L., Munfaridah, N., Ali, M., Rosyidah, F. U. N., & Indrasari, N. (2020). The effect of project based learning-STEM on problem solving skills for students in the topic of electromagnetic induction. *Journal of Physics: Conference Series*, *1521*(2). https://doi.org/10.1088/1742-6596/1521/2/022025

Perdana, R., Apriani, A.-N., Richardo, R., Rochaendi, E., & Kusuma, C. (2021). Elementary students' attitudes towards STEM and 21st-century skills. *International Journal of Evaluation and Research in Education*, *10*(3), 1080–1088. https://doi.org/10.11591/IJERE.V10I3.21389

Peters, M. D. J., Marnie, C., Tricco, A. C., Pollock, D., Munn, Z., Alexander, L., McInerney, P., Godfrey, C. M., & Khalil, H. (2020). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis*, *18*(10), 2119–2126. https://doi.org/10.11124/JBIES-20-00167

Phandini, I., Miharja, F. J., Husamah, H., Fauzi, A., & Nuryady, M. M. (2023). STEM-PBL integrative electronic module: Is that effective in improving students' critical thinking skills? *Jurnal Inovasi Pendidikan IPA*, *9*(2), 118–126. https://doi.org/10.21831/jipi.v9i2.60871

Pollock, D., Peters, M. D. J., Khalil, H., McInerney, P., Alexander, L., Tricco, A. C., Evans, C., de Moraes, É. B., Godfrey, C. M., Pieper, D., Saran, A., Stern, C., & Munn, Z. (2023). Recommendations for the extraction, analysis, and presentation of results in scoping reviews. *JBI Evidence Synthesis*, *21*(3), 520–532. https://doi.org/10.11124/JBIES-22-00123

Pramesti, D., Probosari, R. M., & Indriyanti, N. Y. (2022). Effectiveness of Project Based Learning Low Carbon STEM and Discovery Learning to Improve Creative Thinking Skills. *Journal of Innovation in Educational and Cultural Research*, *3*(3), 444–456. https://doi.org/10.46843/jiecr.v3i3.156

Pratiwi, A. N., Aisyah, N., Somakim, S., & Kamran, M. (2023). STEM-based approach: A learning design to improve critical thinking skills. *Al-Jabar : Jurnal Pendidikan Matematika*, *14*(1), 225–237. https://doi.org/10.24042/ajpm.v14i1.18054

Putri, N., Rusdiana, D., & Suwarma, I. R. (2020). Enhanching physics students' creative thinking skills using CBL model implemented in STEM in vocational school. *Journal of Physics: Conference Series*, *1521*(4). https://doi.org/10.1088/1742-6596/1521/4/042045

Quyen, K. T., Bien, N. Van, & Thuan, N. A. (2023). Micro: bit in Science Education: A Systematic Review. *Jurnal Penelitian Dan Pembelajaran IPA*, *9*(1), 1. https://doi.org/10.30870/jppi.v9i1.19491

Rabbani, G. F., Maulina, H., Herlina, K., & Sri, S. (2024). *An Introduction to the Level of Inquiry Model : Validity and Practicality of Inquiry STEM-Based Learning Sequence e-Worksheet to Stimulate Student Communication Skill*. *9*(1), 1–13. https://doi.org/10.26737/jipf.v9i1.3722

Rachmadtullah, R., Purnaningrum, E., & Suharni, S. (2023). Elementary School Students' Perceptions of STEM-Based Mobile Learning Applications. *Al Ibtida: Jurnal Pendidikan Guru MI*, *10*(2), 178. https://doi.org/10.24235/al.ibtida.snj.v10i2.12387

Rahayu, M., Distrik, I. W., & Suyatna, A. (2023). Developing STEM Electronic Student Worksheet with Problem-Based Learning to Enhance Communication Skills. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *8*(2), 315. https://doi.org/10.24042/tadris.v8i2.16823

Rahmawati, L., Juandi, D., & Nurlaelah, E. (2023). A meta-analysis on the effectiveness of the stem approach on students' mathematical creative thinking ability. *Al-Jabar : Jurnal Pendidikan Matematika*, *14*(1), 109–120. https://doi.org/10.24042/ajpm.v14i1.16637

Rahmawati, Y., Ridwan, A., Hadinugrahaningsih, T., & Soeprijanto. (2019). Developing critical and creative thinking skills through STEAM integration in chemistry learning. *Journal of Physics: Conference Series*, *1156*(1). https://doi.org/10.1088/1742-6596/1156/1/012033

Rajibussalim, R., Rahmayani, E., & Irwandi, I. (2018). Utilising Investigative Science Learning Environment (ISLE) based STEM module for enhancing students' understanding of Physics concepts. *Journal of Physics: Conference Series*, *1120*(1). https://doi.org/10.1088/1742-6596/1120/1/012086

Ramadini, F. D. Des, & Muttaqiin, A. (2023). Validity and Practicality of the STEM-Critical Thinking Video in Science Education: Hydraulic Lift. *JIPF (Jurnal Ilmu …*, *8*(2), 154–167. https://journal.stkipsingkawang.ac.id/index.php/JIPF/article/view/3680

Ramísio, P. J., Pinto, L. M. C., Gouveia, N., Costa, H., & Arezes, D. (2019). Sustainability Strategy in Higher Education Institutions: Lessons learned from a nine-year case study. *Journal of Cleaner Production*, *222*, 300–309. https://doi.org/10.1016/j.jclepro.2019.02.257

Reffiane, F. (2021). Developing an Instrument to Assess Students' Problem-Solving Ability on Hybrid Learning Model Using Ethno-STEM Approach through Quest Program. *Pegem Egitim ve Ogretim Dergisi*, *11*(4), 1–8. https://doi.org/10.47750/pegegog.11.04.01

Reffiane, F., Sudarmin, Wiyanto, & Saptono, S. (2021). Developing an Instrument to Assess Students' Problem-Solving Ability on Hybrid Learning Model Using Ethno-STEM Approach through Quest Program. *Pegem Egitim ve Ogretim Dergisi*, *11*(4), 1–8. https://doi.org/10.47750/pegegog.11.04.01

Restanti, M. A., Hasnunidah, N., Suyatna, A., & Abdurrahman, A. (2023). Production and Utilization of Moodle-Based e-Learning to Enhance Higher-Order Thinking Skills with the STEM Approach. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *8*(2), 237. https://doi.org/10.24042/tadris.v8i2.19298

Rohimah, S. M., Darhim, D., & Juandi, D. (2022). A local instructional theory (LIT) for teaching linear equation through STEM instruction. *Jurnal Elemen*, *8*(2), 340–351. https://doi.org/10.29408/jel.v8i2.4727

Rukayah, Daryanto, J., Atmojo, I. R. W., Ardiansyah, R., Saputri, D. Y., & Salimi, M. (2022). Augmented Reality Media Development in STEAM Learning in Elementary Schools. *Ingenierie Des Systemes d'Informationn*, *27*(3), 463–471.

Rungkat, J. A., Jeujanan, A., Wola, B. R., & Warouw, Z. W. M. (2023). Development of STEM-based Science E-Module on the Human Excretory System Topic. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 6548–6556. https://doi.org/10.29303/jppipa.v9i8.4437

Saefullah, A., Suherman, A., Utami, R. T., Antarnusa, G., Rostikawati, D. A., & Zidny, R. (2021). Implementation of PjBL-STEM to Improve Students' Creative Thinking Skills On Static Fluid Topic. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *6*(2), 149. https://doi.org/10.26737/jipf.v6i2.1805

Saputra, H., Fauzan, T. A., & Dharmayanti, D. (2023). Bibliometric Analysis of Near Field Communication Technology Using Vosviewer Application With Publish or Perish. *Journal of Engineering Science and Technology*, *18*(6), 3155–3166.

Sarah, L. L., Ananto, Y., Octonary, D., & Nussifera, L. (2022). Implementing web-based e-scaffolding enhances learning (ESEL) at the center of mass conceptual understanding. *Jurnal Inovasi Pendidikan IPA*, *8*(1), 37–46. https://doi.org/10.21831/jipi.v8i1.46476

Sari, J. M., & Purwanta, E. (2021). The Implementation of Artificial Intelligence in STEM-Based Creative Learning in the Society 5.0 Era. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *6*(2), 433–440. https://doi.org/10.24042/tadris.v6i2.10135

Sari, R. P., Mauliza, M., & El Islami, R. A. Z. (2020). Performance and Peer Assessment Analysis Towards Students' Scientific Work Through Stem-Based Virtual Laboratory Learning. *JTK (Jurnal Tadris Kimiya)*, *5*(2), 204–212. https://doi.org/10.15575/jtk.v5i2.9858

Shalikhah, N. D., & Nugroho, I. (2023). Implementation of Higher-Order Thinking Skills in Elementary School Using Learning Model, Media, and Assessment. *AL-ISHLAH: Jurnal Pendidikan*, *15*(3), 3978–3990. https://doi.org/10.35445/alishlah.v15i3.3091

Shidiq, A. S., Permanasari, A., & Hernani. (2020). Chemistry Teacher's Perception toward STEM Learning. In *ACM International Conference Proceeding Series* (pp. 40–43). https://doi.org/10.1145/3392305.3396901

Shidiq, A. S., Purnamasari, A., Hernani, & Hendayana, S. (2022). Contemporary Hybrid Laboratory Pedagogy: Construction of a Simple Spectrophotometer with STEM Project-Based Learning to Introduce Systems Thinking Skills. *Asia Pacific Journal of Educators and Education*, *37*(2), 107–146. https://doi.org/10.21315/apjee2022.37.2.6

Sinurat, H. A. Y., Syaiful, S., & Muhammad, D. (2022). The Implementation of Integrated Project-Based Learning Science Technology Engineering Mathematics on Creative Thinking Skills and Student Cognitive Learning Outcomes in Dynamic Fluid. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *8*(1), 83–94. https://doi.org/10.21009/1.08108

Siregar, Y. E. Y., Rahmawati, Y., & Suyono. (2023). The Impact of an Integrated Steam Project Delivered Via Mobile Technology on the Reasoning Ability of Elementary School Students. *Journal of Technology and Science Education*, *13*(1), 410–428. https://doi.org/10.3926/jotse.1446

Spellman, K. V. (2015). Educating for Resilience in the North: building a toolbox for teachers. *Ecology and Society*, *20*(1).

Subali, B., Ellianawati, Faizah, Z., & Sidiq, M. (2023). Indonesian national assessment support: Can RE-STEM Android app improve students' scientific literacy skills? *International Journal of Evaluation and Research in Education*, *12*(3), 1399–1407. https://doi.org/10.11591/ijere.v12i3.24794

Subiki, S., Elika, E. T. P., & Anggraeni, F. K. A. (2023). The Effect of the Project-Based Learning Model with the STEAM Approach on Learning Outcomes of High School Students the Subject of Material Elasticity. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 745–751. https://doi.org/10.29303/jppipa.v9i2.2926

Sukendra, I. K., Widana, I. W., & Juwana, I. D. P. (2023). Senior High School Mathematics E-Module Based on STEM Orienting to Higher Order Thinking Skills Questions. *JPI (Jurnal Pendidikan Indonesia)*, *12*(4), 647–657. https://doi.org/10.23887/jpiundiksha.v12i4.61042

Sukma, I. M., Marianti, A., & Ellianawati. (2023). Development of an E-Book Based on STEM-Integrated Creative Problem Solving on Environmental Change Material to Improve Students' Critical Thinking and Creative Thinking. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 6111–6121. https://doi.org/10.29303/jppipa.v9i8.4356

Sukma, M., & Halim, A. (2022). Implementation of e-Learning Module Based on Science Technology Engineering Mathematics on Solar Cells Topic. *Jipf (Jurnal Ilmu Pendidikan Fisika)*, *7*(1), 60–70.

Sulistiyowati, S., Abdurrahman, A., & Jalmo, T. (2018). The Effect of STEM-Based Worksheet on Students' Science Literacy. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *3*(1), 89. https://doi.org/10.24042/tadris.v3i1.2141

Sumin, S., Salleh, K. M., & Nurdin, N. (2021). The effect of external factors moderated by digital literacy on the actual use of e-learning during the Covid-19 pandemic in Islamic universities in Indonesia. *REID (Research and Evaluation in Education)*, *7*(2), 132–144. https://doi.org/10.21831/reid.v7i2.44794

Suripto, S., Fabirah, N. R., Nanna, A. W. I., & Bua, M. T. (2023). Science, Technology, Engineering, and Mathematics (Stem) in Exploring Students' Critical Thinking Skills. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *12*(1), 319. https://doi.org/10.24127/ajpm.v12i1.6044

Susilayati, M., & Hardyanto, W. (2024). The research trends and contributions of science education during the COVID- - pandemic : A narrative systematic literature review of publications in selected journals. *Review of Education*, *12*(1), 1–50. https://doi.org/10.1002/rev3.3464

Susilayati, M., Hardyanto, W., Supriyadi, & Widiyatmoko, A. (2023). The Research Trends and Contribution of Science Education amidst Covid-19 Pandemic: A Narrative Systematics Literature Review. *Review of Education*, *In Product*.

Susilowati, N. E., Muslim, M., Efendi, R., & Samsudin, A. (2022). What is the Most Impressive Treatment to Foster Students' Creative Thinking Skills? A Meta-Analysis and Bibliometric Review. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *7*(2), 201–219. https://doi.org/10.24042/tadris.v7i2.12690

Sutiani, A., & Pasaribu, C. J. T. (2023). Fostering Scientific Literacy through Integrated STEM Teaching Materials on Basic Laws of Chemistry. *JTK (Jurnal Tadris Kimiya)*, *8*(1), 95–103. https://doi.org/10.15575/jtk.v8i1.25833

Syukri, M., Herliana, F., Maryono, Ngadimin, & Artika, W. (2023). Development of Physics Worksheet based on STEM integrating Engineering Design Process (EDP) through Guided Inquiry Model to Improve Students' Critical Thinking. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *9*(2), 225–236. https://doi.org/10.21009/1.09205

Syukri, M., Rahmi, M., Saminan, S., Artika, W., & Subramaniam, T. S. (2022). Virtual Lab Based on STEM Approach: Is It Effective to Enhance Students Concept of Temperature and Heat? *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *11*(2), 151–164. https://doi.org/10.24042/jipfalbiruni.v11i2.12545

Tan, S. (2023). Exploiting Disruptive Innovation in Learning and Teaching. In K. Rajaram (Ed.), *Learning Intelligence: Innovative and Digital Transformative Learning Strategies* (pp. 149–176). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-9201-8_4

Thuy, N. T. T., Bien, N. Van, & Quy, D. X. (2020). Fostering Teachers' Competence of the Integrated STEM Education. *Jurnal Penelitian Dan Pembelajaran IPA*, *6*(2), 166. https://doi.org/10.30870/jppi.v6i2.6441

Towip, T., Widiastuti, I., & Budiyanto, C. W. (2022). Students' Perceptions and Experiences of Online Cooperative Problem-Based Learning: Developing 21st Century Skills. *International Journal of Pedagogy and Teacher Education*, *6*(1), 37. https://doi.org/10.20961/ijpte.v6i1.56744

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., … Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, *169*(7), 467–473. https://doi.org/10.7326/M18-0850

van Eck, N. J., & Waltman, L. (2023). VOSviewer Manual version 1-6-19. In *Leiden: Univeristeit Leiden* (Issue January). http://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.1.pdf

W, K. A., Sukaryawan, M., & Ad'hiya, E. (2021). The effect of STEM approach e-module-topic of free-range chicken eggs productivity on student learning outcomes in entrepreneurship courses in the era of the industrial revolution 4.0. *Jurnal Pendidikan Kimia*, *13*(3), 261–268. https://doi.org/10.24114/jpkim.v13i3.29931

Wandani, S., Setyansah, R. K., & Masfingatin, T. (2023). Development of Mathematics e-Modules based on PjBL STEM on Materials Constructing Flat Side Spaces to Improve Mathematical Communication Ability of Junior High School Students. *AL-ISHLAH: Jurnal Pendidikan*, *15*(1), 533–548. https://doi.org/10.35445/alishlah.v15i1.2497

Wardani, D. S., Kelana, J. B., & Jojo, Z. M. M. (2021). Communication Skills Profile of Elementary Teacher Education Students in STEM-based Natural Science Online Learning. *Profesi Pendidikan Dasar*, *8*(2), 98–108. https://doi.org/10.23917/ppd.v8i2.13848

Wibowo, F. C. (2021). Interactive Book Augmented Reality (IBAR) for lesson physics on STEM. In *Journal of Physics: Conference Series* (Vol. 2019, Issue 1). https://doi.org/10.1088/1742-6596/2019/1/012039

Wibowo, F. C., Nasbey, H., Sanjaya, L. A., Darman, D. R., & Ahmad, N. J. (2021). Interactive Book Augmented Reality (IBAR) for lesson physics on STEM. *Journal of Physics: Conference Series*, *2019*(1). https://doi.org/10.1088/1742-6596/2019/1/012039

Widyasmah, M., Abdurrahman, & Herlina, K. (2020). Implementation of STEM Approach Based on Project-based Learning to Improve Creative Thinking Skills of High School Students in Physics. *Journal of Physics: Conference Series*, *1467*(1). https://doi.org/10.1088/1742-6596/1467/1/012072

Wiyono, K., Sury, K., Hidayah, R. N., Nazhifah, N., Ismet, I., & Sudirman, S. (2022). STEM-based E-learning: Implementation and Effect on Communication and Collaboration Skills on Wave Topic. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *8*(2), 259–270. https://doi.org/10.21009/1.08208

Yennita, Y., Zulirfan, Z., Hermita, N., & Hakim, L. (2022). Validation and Testing of STEM Project-Based Virtual Learning Modules to Improve Higher-Level Thinking Skills. *Jurnal Ilmu Pendidikan Fisika*, *7*(2), 145–156. https://doi.org/10.26737/jipf.v7i2.2420

Yuberti, Y., Komikesari, H., & Lubis, M. (2022). Developing STEM-Based Interactive E-Books to Improve Students' Science Literacy. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *7*(1), 177–188. https://doi.org/10.24042/tadris.v7i1.10914

Yuliati, L., Yogismawati, F., Purwaningsih, E., & Affriyenni, Y. (2021). Concept acquisition and scientific literacy of physics within inquiry-based learning for STEM Education. *Journal of Physics: Conference Series*, *1835*(1). https://doi.org/10.1088/1742-6596/1835/1/012012

Yunianta, T. N. H., Herman, T., Wizhar, B. Al, & Kurniawan, M. A. F. (2023). Development of Mathematics E-Module Using Kodular and Flipbook for Junior High School Students: Differences. *Jurnal Didaktik Matematika*, *10*(1), 1–16. https://doi.org/10.24815/jdm.v10i1.29730

Yunzal, Jr., A. N., & Casinillo, L. F. (2020). Effect of Physics Education Technology (PhET) Simulations: Evidence from STEM Students' Performance. *Journal of Education Research and Evaluation*, *4*(3), 221. https://doi.org/10.23887/jere.v4i3.27450

Zainil, M., Kenedi, A. K., Rahmatina, Indrawati, T., & Handrianto, C. (2023). The influence of a STEM-based digital classroom learning model and high-order thinking skills on the 21st-century skills of elementary school students in Indonesia. *Journal of Education and E-Learning Research*, *10*(1), 29–35. https://doi.org/10.20448/jeelr.v10i1.4336

Isa, S. S., Mohd, J. S., Isa, S. S., Ali, A., & Jamaludin, N. L. (2024). Satisfaction of Mobility Students on Interdisciplinary Approach in Awareness Program for Forest Conservation and Recycle Activities. *Pakistan Journal of Life and Social Sciences (PJLSS)*, *22*(2).

Jam, F., Donia, M., Raja, U., & Ling, C. (2017). A time-lagged study on the moderating role of overall satisfaction in perceived politics: Job outcomes relationships. Journal of Management & Organization, 23(3), 321-336. doi:10.1017/jmo.2016.13