TEM Journal. Volume 13, Issue 3, pages 1793-1804, ISSN 2217-8309, DOI: 10.18421/TEM133-08, August 2024.

Systematic Review of Technology-Based STEM Education Research in the United States

Lijun Cheng [1], Riew Kinoshita [1]

[1] *Faculty of Education, Chiba University,1-33, Yayoicho, Inage-ku, Chiba-shi, Chiba, 263-8522, Japan*

Abstract **– This study reviewed technology-based STEM education research papers published during 2015–2022. Data collection and analysis were conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. Eighty-two papers were analyzed. The findings provide a summary of research trends over the past eight years. Technology education effects on STEM education participation are no longer emphasized when assessing knowledge and skills. Rich research contents, such as environment and experience-related research are emphasized. Furthermore, this study clarified the characteristics of technology education research distribution in various stages of general education and revealed some important research concerns.**

Keyword **– Educational stage, PRISMA, research trends, student-centered learning.**

1. Introduction

Increasingly, technologies are integrated into education along with scientific and technological development. Student-centered STEM education, which originated in the United States, attaches great importance to technology education. It continues to mature and improve [1].

DOI: 10.18421/TEM133-08
https://doi.org/10.18421/TEM133-08

Corresponding author: Lijun Cheng,
Faculty of Education, Chiba University,1-33, Yayoicho, Inage-ku, Chiba-shi, Chiba, 263-8522 Japan
Email: 23e2a001@student.gs.chiba-u.jp

Received: 27 January 2024.
Revised: 17 May 2024.
Accepted: 04 June 2024.
Published: 27 August 2024.

Important progress has been made in STEM education during almost two decades. The first handbook of research on STEM education has collected primary outcomes from the accumulated published research. The handbook addresses the STEM education work and research framework, which involves integration of science, technology, engineering, and mathematics [2]. That integration demands the inclusion of at least two disciplines [3]. However, these research studies emphasized better help for understanding STEM education contents. Practical aspects of those studies were limited [2]. Furthermore, although technology has garnered more attention recently, it is often linked with engineering [4]. Consequently, technology's importance as an educational subject has been overlooked.

The research papers collected for this study do not specifically describe studies examining technology education with vocational education content, but technology education as vocational education is an important issue that must be elucidated as a separate topic [5]. The study specifically examines general education: primary, secondary, and higher education [6]. With this constraint as a reference, this research analysis using the literature review method examines research related to STEM education in the United States at various stages based on technology education.

The term STEM originated from STEM, first used by the National Science Foundation (NSF) in the 1990s to refer to fields and courses related to science, technology, engineering, and mathematics [7]. Especially during that period, as science came to be regarded as the application of ideas in everyday life, the science curriculum shifted to more interdisciplinary approaches [8]. Furthermore, mathematicians, scientists, and educators created professional organizations for the exchange of their ideas. Although no consensus-based definition exists for an integrated STEM curriculum, the generally agreed upon curriculum revolves around experiences interconnecting science, technology, engineering, and mathematics to some degree [2].

In 2001, the American Association for the Advancement of Science (AAAS) published its two-volume *Atlas of Science Literacy* as a part of Project 2061, which mapped the K–12 science curriculum. It includes the topics, scope and sequence, standards, benchmarks, instructional design, training, resources, and assessment [9]. These volumes highlight the dynamic nature of science and its interdisciplinary connections with technology and mathematics [9]. *The National Science Education Standards* [10] and mathematics, along with the *Curriculum and Assessment Standards for School Mathematics*, have further supported the integration of these subjects [11]. Nationwide standards established by professional associations were subsequently promoted to states and regions. Judith Lamarie, the Associate Director for Education and Human Resources at the National Science Foundation, created the STEM acronym to be more appealing: it stands for science, technology, engineering, and mathematics [12]. The National Science Foundation's STEM research and development activities created new standards emphasizing connections among the four STEM disciplines [13]. *The National Science Education Standards* then underwent a review process in the United States.

In 2011, the National Research Council (NRC) developed its *Framework for K–12 Science Education Practices, Crosscutting Concepts, and Core Ideas* [14].

In April 2013, the *Next Generation Science Standards* (NGSS) were published [15]. Their goal was encouragement of students to think critically, collaborate, solve real-world problems, and use evidence-based reasoning to apply their knowledge.

In 2015, with the STEM Education Act, the STEM education definitions were standardized. Based on these definitions, STEM was expanded and redefined. Moreover, other disciplines were developed and added [16].

During the STEM development process, the *National Science Education Standards* were presented to serve as a theoretical basis and to indicate technology as an integral part of the K–12 science curriculum. For the first time, recommendations were made to incorporate technology and technical design into scientific standards [10].

In 2000, the *Standards for Technological Literacy: Technology Research Content* were published around the same time as the Atlas of Science Literacy was proposed by the AAAS in 2001 [17]. The standards emphasize integration of technologies with other areas of study such as mathematics and science to help students understand the diverse and often complex connections among various technologies [17].

This standard emphasizes learning of the basic concepts of technology and their application in engineering design. Thereby, students can better evaluate the technological tradeoffs confronting society. To incorporate technology in engineering design experiences, it is important to support the development of 21st-century skills. Specifically, the standard addresses activities related to the design process: modeling, testing, investigation, analysis, and decision-making. In fact, all of those activities are supported by technology [16].

Relations among the four disciplines can be characterized succinctly: mathematics and science provide a contextual background for technology; also, technology supports engineering design implementation. Technology therefore plays a salient role in integrating the respective STEM disciplines.

The current research status of STEM education based on technology education is that technology is recognized as supporting teaching methods. Technical methods have been introduced into the classroom, especially after the COVID-19 pandemic. Distance learning and inversion learning have increased, with technology applied specifically for teaching [18]. Increasingly, people recognize the importance of technology in education. Nevertheless, there are limitations to recognizing and assessing technology education in STEM [19]. Especially, identifying specific subjects' attributes and characteristics is fundamentally important for supporting better integration of STEM education [19]. In other words, no comprehensive review of technology-based STEM education research exists.

Therefore, this study specifically examines the current STEM education achievements and issues based on technology education, while providing additional data and analysis through a larger-scale systematic review.

2. Methodology

Systematic reviews are intended to assess and interpret all applicable research related to a certain topic, question, or phenomenon [20]. The aim of such a review is to answer specific questions based on a clear, systematic, and replicable search strategy, using inclusion and exclusion criteria to identify studies to be included and excluded. After including studies, the review should code and extract data to synthesize findings. Subsequently, the findings must be applied practically, with discussion of gaps and contradictions.

To prevent bias, systematic reviews must follow specific standards and processes. The guidelines, designated as PRISMA, are provided with a detailed list and flow chart of studies. They are given a comprehensive list and flowchart of studies.

The *PRISMA* Statement, a reporting guideline created to address poor systematic review reporting issues, was published in 2009. The recommendations include a 27-item checklist, with each item providing supplemental reporting guidance and reporting examples. These recommendations have been widely recognized and adopted. The 2020 edition contents have been upgraded. The checklist has been expanded to 41 items. The PRISMA 2020 guidelines provide mixed methods reporting standards for systematic reviews that include quantitative and qualitative studies. However, we recommend consulting the reporting guidelines for presenting and synthesizing qualitative data [21].

Systematic reviews can synthesize knowledge and can inform research priorities. Questions that individual studies cannot answer can be addressed using this method. In addition, issues from preliminary studies that must be corrected are identifiable by them. Furthermore, a systematic review can generate or evaluate theories about how and why phenomena occur. Systematic reviews are often applied in medical fields and other areas such as psychology, sociology, educational science, and educational management. In recent years, the numbers of STEM education reviews and systematic reviews in the international literature have increased gradually. Moreover, the wide application of systematic review research to educational science has attracted the attention of many researchers [22]. In the literature, systematic review studies dealing with STEM education from different perspectives have generally intensified since 2018. Therefore, this study used the latest version of PRISMA standards for data filtering and analysis.

3. Research Questions

This study, using a systematic analysis of reports published during the past eight years, analyzed STEM education achievements and issues based on technology education. The following research questions were specifically examined.

1. What are eight-year trends of technology-based STEM education related research?
2. What are technology-based STEM education research outcomes in the United States?
3. What are technology-based STEM education research issues in the United States?

4. Data Collection

To ensure the quality of research data, this study collected research-related literature from the four most commonly and authoritatively used databases: ERIC, Google Scholar, Scopus, and Web of Science.

These four databases were selected for their wide range of topics and high-quality reports of impactful research. Furthermore, these databases are influential in international academic fields.

4.1. Database

In ERIC, sponsored by the Institute of Educational Sciences of the U.S. Department of Education, over 80% of indexed journals contain education-related articles. Google Scholar, a free academic search engine, was developed by Alphabet Inc. Because it covers a broader range of literature worldwide, it is often used as a search source for data citations. Scopus, an abstract and citation database launched by Elsevier Publishing Co. in 2004, includes sources of three types: book series, journals, and business magazines. Using Scopus, one can access peer-reviewed journals in the life, social, physical, and health sciences.

Finally, initially produced by the Institute for Scientific Information, Web of Science is a platform provided by Clarivate Analytics (Clarivate plc.). It facilitates access to multiple databases, academic journals, conference proceedings, and other literature for reference and citation data. The evaluation of journal quality is based mainly on Journal Citation Reports (JCR), which provides the journal's impact factor, ranking, citation distribution, and other indicators. Additionally, it has journal evaluation process and standards.

The systematic review conducted for this study is expected to provide a comprehensive retrieval platform based on high-credibility academic coverage of the four data groups.

4.2. Search Strategy

As part of initial identification of the sample literature, the broadest search was conducted in the four databases. Searches were conducted multiple times using the keywords "technology education" and "STEM education," connecting them with "AND" or "OR" or without these two words, and by performing multiple searches by changing the positions of keywords before and after the conjunction. Although the search target is education, some contents in other fields are expected to be included in the screening process, especially literature using similar vocabulary in the medical field. This data filtering was based on results obtained for 2015–2022 because the U.S. STEM Education Act came into effect on October 7, 2015, after being signed by U.S. President Obama. Under this law, the English terminology for STEM education remained unchanged, but computer science was added.

After enactment of this law, federal agency definitions of STEM education in computer science became more formal and standardized. The STEM education fields in the United States were funded primarily by the National Science Foundation, the U.S. Department of Energy, and other agencies during the ensuing eight years. This study used that research as its primary data source. After the first filtering, 10,912 documents were obtained based on results obtained using the four data platforms. Representative reports of the literature were selected mainly based on recurring themes. Redundancy was avoided. Because of the exploratory nature of the study, the search was not intended to encompass all conceivable outcomes. The search process was straightforward and conducted by the authors at different times. The papers were selected from other sources to meet the goals of this study.

5. Procedure

The literature collection process strictly followed the PRISMA 2020 checklist for data filtering. The resulting flow chart and filtering conditions are presented respectively in Figure 1 and Table 1.

Figure 1 presents the number of references filtered out during the screening process and the number of retained documents.

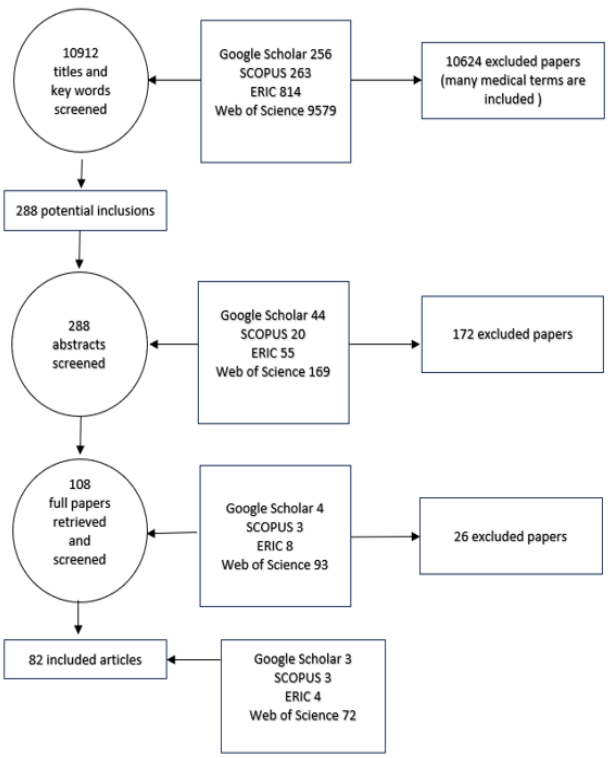

Figure 1. PRISMA flowchart for data extraction.

Filtering details are shown in Table 1.

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Written in English	Not written in English
Studies available in full text	Studies unavailable in full text
Research areas involved in STEM/STEAM education	Research areas outside of STEM/STEAM education
Research is technology-based	Research is not technology-based
Study regions scoped in the United States	Study regions in other countries outside of the United States
Study area based only on the United States without several countries mixed	Study area based on several countries including the United States
Both technology-based and STEM education	Neither technology-based nor related to STEM education
Publication date of the paper within the detected range	Publication date of the paper exceeds the detected range
Research based on general education	Research based on teacher training

6. Results

The systematic review analyzed 82 documents to provide meaningful data to address the research questions. Appendix A is a list of the reviewed articles. Findings pertaining to the primary research questions are presented succinctly below.

Regarding research question 1, research on technology-based STEM education during the eight years is varied, although the research specifically emphasizes learning. However, the emphases have changed somewhat. The analysis results based on the research content are presented in Figure 2 below.

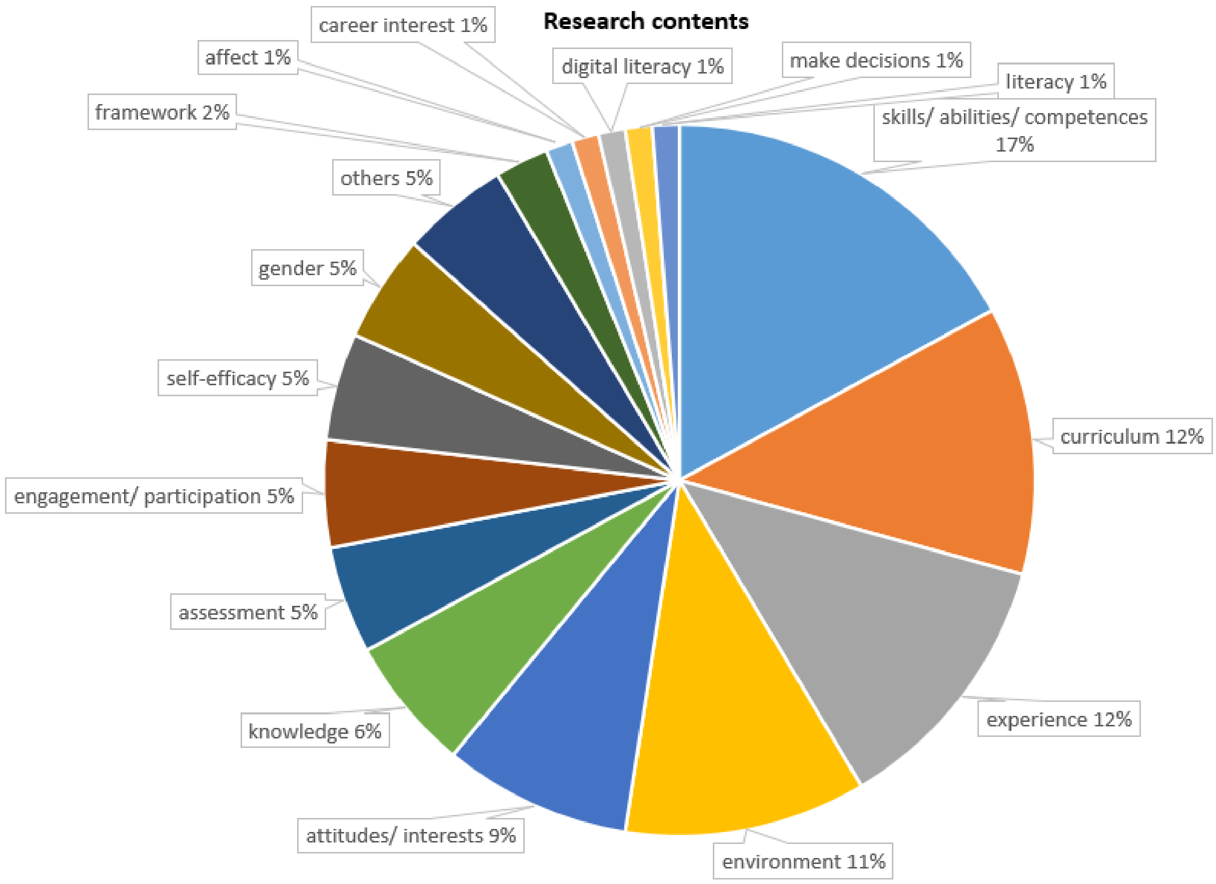

Figure 2. Distribution of research contents.

From Figure 2, research in STEM education exhibits diverse content trends.

Specifically, the research contents no longer specifically aim at a traditional assessment of knowledge (6%) and skills (17%). Furthermore, research on learning-related hardware, such as the curriculum (12%) and learning environment (11%), also produced a large ratio. Many studies emphasized the study of learners' learning participation at 5% and attitude or interest at 9%. Research addressing learner experiences in research contents accounted for 12%. In addition to these studies which specifically evaluated learning assessment, learners' self-efficacy, gender personality differences, and other aspects, data were also more or less distributed.

In summary, technology-based STEM education has changed toward the use of technology for transformative learning.

Regarding research question 2, three primary outcomes were found from the literature.

First, a change occurred in the understanding of technology. According to results obtained from analysis of literature data (reference materials), overall, many studies were conducted within schools (66), with fewer studies conducted outside schools (13), or both (3). In other words, results clarified that studies would be done mainly at schools.

Additionally, we were able to extract the educational directions of practical research (63), theory research (9), and trend surveys (10).

Results show that skills, curriculum, experience, and environment account for over half of the content (43/82).

In addition, many results were revealed in the research. Specifically, technology-based STEM education is being enriched. This enrichment refers not only to the integration of richer technical content; it highlights the importance of technology as an educational tool and its integration with education. Furthermore, by integrating this accurate or currently used technology into instruction, we can connect teaching and reality and can gain genuine social relationships in the academic environment. In other words, technology-based STEM education can extend learning outcomes in the classroom to environments beyond the school. It can also be said that teachers no longer provide information unilaterally but instead facilitate problem-solving, communication, and collaboration with learners. At the same time, greater emphasis is placed on practical skills and experience rather than merely on the teaching of knowledge. Moreover, the learning environment had become a supportive space for creativity and innovation, with increasing opportunities for knowledge application and creation.

Second, based on the division of various general education levels (Table 2), the characteristics of STEM education (Table 3) were clarified based on technology education at each stage.

Table 2. Distribution of references in various educational stages (number of references)

<table>
<tr><td colspan="5">Level (82)</td></tr>
<tr><td rowspan="5">K–20 (1)</td><td colspan="4">Higher education (14)</td></tr>
<tr><td rowspan="4">K–12 (16)</td><td rowspan="2">Secondary education (5)</td><td>High school (11)</td><td rowspan="2">Youth (7)</td></tr>
<tr><td>Middle school (10)</td></tr>
<tr><td colspan="3">Elementary education (11)</td></tr>
<tr><td colspan="3">Early childhood education (6)</td></tr>
<tr><td colspan="2">Others</td><td colspan="3">Students (1)</td></tr>
</table>

Table 3. Summary of characteristics of each stage

Level	Characteristic
K–20 (1)	Emphasize cultivation of innovation and creativity to prevent skill differences
Higher education (14)	Improve the environment and increase experiential learning to improve opportunities to participate in design
K–12 (16)	Technology means become diverse
Secondary education (5)	Improve learning experience and application skills to reduce the skill gap
Youth (7)	Enhance engagement without classroom/school experience
High school (11)	Emphasize problem-solving skills and self-efficacy
Middle school (10)	Expand knowledge, skills, attitude and interest
Elementary education (11)	Improve attitude and cultivate interest
Early childhood education (6)	Contact with STEM education
Others (1)	Student performance and engagement

Table 2 shows that, in research assessing general education, especially STEM education, results indicate that the learning content of technical education started with increasing opportunities for contact with STEM education from preschool education to higher education. In the introductory process of preparing for entering society, preparation here refers to narrowing the skill gap separating real society and school education to cultivate more proactive innovation and design capabilities. As a supplement, the breadth of training is also expanded in addition to fundamentally important knowledge and skills related to technology. Attitude, learning motivation, and emotional content were also integrated into the technical learning content.

In addition, the technical education contents are gradually enriched. In other words, more types of technologies were introduced into the classroom to support technical education.

Third, various studies have elucidated different perspectives on technology education, with teachers and learners taking different positions. Using technology as a teaching tool has become more convenient and enriching for teachers. However, learners have become able to connect technology experiences with reality, thereby narrowing the competency gap separating school and real society and transforming technology into a rich learning experience for building a better social community.

Regarding research question 3, several research issues were found in the literature after data analysis.

First, teachers faced difficulties in selecting teaching materials and in creating an environment. Specifically, because of the highly rapid development of technology, the kind of technology contents to integrate and the means of achieving student-centered learning in the classroom have become topics for teachers when introducing STEM education. In other words, creating environments in which teachers and learners can share mutual experiences was not an easy task.

Secondly, to bridge the gap separating classroom education and practical application, the emphasis is on individual skills such as computational thinking, problem-solving, and critical thinking. The main objective is to help learners better adapt to society. Nevertheless, comprehensive research investigating the capabilities that help learners become entrepreneurial and innovative remains insufficient.

Third, technology-based STEM education often uses manufacturing and design activities to enhance learning experiences and learner participation. However, judging from research contents found at the general education stage, because of inadequate communication with social groups, relevance and a lasting sense of experience were insufficient to stimulate interest and participation among a broad and diverse range of students.

7. Discussion

Based on the integration of STEM education, our research specifically examined contents related to technology education and strengthened the contents of technology education in earlier research.

1. It is insufficient and misleading to understand technology-centered integration in the context of the past 20 years in the United States. Learning in technology education was based on content rather than means. However, recent education scholars have increasingly devoted attention to contextual issues [23].

Technological evolution and classroom complexity were better understood. No one-size-fits-all technology can resolve all present and expected difficulties. Effective education requires understanding of the application of appropriate, situation-specific strategies [2]. These study findings also prove that technology education promotes integration among the four disciplines of STEM education through contextual issues such as design practice and the maker movement.

2. Instruction at each stage was intended to be student-centered learning. It emphasized that teachers created an environment to improve learners' sense of experience and higher-level thinking and problem-solving abilities. It also encouraged teachers to become collaborators in thinking and problem-solving with learners [24]. Moreover, the literature described out-of-school learning through a combination of formal and informal education and even by engaging professionals to help learners integrate education and real-world issues by extending the reach of their communities and by engaging in more authentic experiences. Combined, the environment can inspire learning [25].

3. Using technology more actively to resolve social difficulties related to our life or world, especially through continuous trial and error, helped learners improve their creativity and learning outcomes according to their needs. It also cultivated capabilities to provide new technologies steadily and consistently to build a sustainable society [26].

In addition, our research revealed more detailed technology contents in STEM education. The chronological development and changes of these contents and the specific characteristics of the research field are based on the general education stage. Furthermore, issues to be faced during the general education stage were highlighted.

8. Conclusion

This study systematically reviews the research literature related to STEM education based on technology education, particularly addressing the content characteristics and issues of technology education. Key findings of our study are given below.

The types of content and assessments of technology education are becoming increasingly abundant. Digital technology was heavily cited in teaching as a core technology. Assessment of STEM education is no longer limited to knowledge and skills. Instead, evaluations use learning motivation, emotion, and other aspects as assessment criteria.

Connecting technology with practical activities related to innovation and design can be useful to integrate the contents science, engineering, and mathematics through technology integration.

However, along with rapid development of technology, one must be cautioned against simultaneous introduction of all technologies into the classroom. Instead, it is necessary to awaken enthusiasm for participating in the integration of disciplines through this experience and through exposure to technology on a broader level. Such an awakening can help learners know how to resolve real-world difficulties, which must be the top priority of education today.

As a supplement, these results are expected to provide a profoundly useful reference for professionals studying and researching technical education, facilitating their promotion of the participation of more technical content in integrating STEM education.

Acknowledgments

This research was supported by the Japan Society for the Promotion of Science under grant number 21K02258. The opinions, findings, conclusions, or recommendations expressed in this material are solely those of the authors and do not necessarily reflect the views of the Japan Society for the Promotion of Science.

References:

[1]. Stieben, M. E., Pressley, T. A., & Matyas, M. L. (2021). Research experiences and online professional development increase teachers' preparedness and use of effective STEM pedagogy. *Advances in Physiology Education*, *45*(2), 191-206. Doi:10.1152/advan.00158.2020

[2]. Johnson, C. C., Mohr-Schroeder, M. J., Moore, T. J., & English, L. D. (Eds.). (2020). *Handbook of Research on STEM Education*. Routledge. Doi:10.4324/9780429021381

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

[4]. International Technology and Engineering Educators Association. (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. ITEEA. Retrieved from: https://www.iteea.org/stel [accessed: 01 January 2024].

[5]. Pavlova, M. (2008). *Technology and vocational education for sustainable development: Empowering individuals for the future*, *10.* Springer Science & Business Media.

[6]. Wikipedia. (2023). Educational stage. Wikipedia. https://en.wikipedia.org/wiki/Educational_stage#cite_note-1 [accessed: 02 January 2024]

[7]. American Association for the Advancement of Science (AAAS). (1989). *Science for all Americans.* Washington, DC: AAAS.

[8]. DeBoer, G. (2019). *A history of Ideas in Science Education.* Teachers College Press.

[9]. American Association for the Advancement of Science (AAAS). (2001). *Atlas of Science Literacy.* Washington, DC: AAAS.

[10]. National Research Council (NRC). (1996). *National science education standards. National Committee on Science Education Standards and Assessment. Board on Science Education, Division of Behavioral and Social Science and Education.* Washington, DC: National Academies Press. Doi:10.17226/4962

[11]. National Council of Teachers of Mathematics, & (NCTM). (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: NCTM.

[12]. Sanders, M. E. (2009). Stem, Stem Education, Stemmania. *The Technology Teacher, 68*(4), P20-26.

[13]. National Governors Association Center for Best Practices, & Council of Chief State School Officers. (2010). *Common core state standards for mathematics.* Washington, DC.

[14]. National Research Council. (2012). *A framework for K-12 science education: Practice, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

[15]. States, N. L. (2013). *Next generation science standard: For states, by states*. Washington, DC: The National Academies Press. Doi:10.17226/18290

[16]. Breiner, J. M. et al. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3-11. Doi:10.1111/j.1949-8594.2011.00109.x

[17]. International Technology Education Association, & (ITEA). (2000). *Standards for technological literacy: Content for the student of technology.* Reston, VA.

[18]. Fung, E. B. et al. (2021). Success of distance learning during 2020 COVID-19 restrictions: A report from five STEM training programs for underrepresented high school and undergraduate learners. *Journal of STEM Outreach*, *4*(3).Doi:10.15695/jstem/v4i3.03

[19]. Ntemngwa, C., & Oliver, J. S. (2018). The Implementation of Integrated Science Technology, Engineering and Mathematics (STEM) Instruction using Robotics in the Middle School Science Classroom. *International Journal of Education in Mathematics Science and Technology*, *6*(1), 12-40.

[20]. Page, M. J. et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery*, *134*, 105906. Doi:10.1016/j.jclinepi.2021.02.003

[21]. Page, M. J. et al. (2021). PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ*, *372*, n160. Doi:10.1136/bmj.n160

[22]. Bedenlier, S., Bond, M., Buntins, K., Zawacki-Richter, O., & Kerres, M. (2020). Facilitating student engagement through educational technology in higher education: A systematic review in the field of arts and humanities. *Australasian Journal of Educational Technology*, *36*(4), 126–150.

[23]. Wu, J., Atit, K., Ramey, K. E., Flanagan-Hall, G. A., Vondracek, M., Jona, K., & Uttal, D. H. (2021). Investigating Students' Learning Through Co-designing with Technology. *Journal of Science Education and Technology*, *30*(4), 529-538. Doi:10.1007/s10956-020-09897-7

[24]. Lavicza, Z. et al. (2022). Developing and Evaluating Educational Innovations for STEAM Education in Rapidly Changing Digital Technology Environments. *Sustainability*, *14*(12), 7237. Doi:10.3390/su14127237

[25]. Hsu, Y.-C., Baldwin, S., & Ching, Y.-H. (2017). Learning through making and maker education. *Techtrends*, *61*, 589-594. Doi:10.1007/s11528-017-0172-6

[26]. Belland, B. R., Kim, C., Zhang, A. Y., Lee, E., & Dinc, E. (2022). Classifying the quality of robotics-enhanced lesson plans using motivation variables, word count, and sentiment analysis of reflections. *Contemporary Educational Psychology*, *69*, 102058. Doi:10.1016/j.cedpsych.2022.102058

Appendix. A Selected Bibliography

This appendix presents the 82 publications of academic papers open-accessed from ERIC, Google Scholar, Scopus and Web of Science grouped into ten groups according to Table 3 above.

Number	Author and Title	Year	Database
	Part I K–20		
1	Perignat, E., & Katz-Buonincontro, J.: STEAM in practice and research: An integrative literature review.	2019	WOS
	Part II Higher education		
2	Choi, G. Y., & Behm-Morawitz, E.: Giving a new makeover to STEAM: Establishing YouTube beauty gurus as digital literacy educators through messages and effects on viewers.	2017	SCOPUS
3	Sinha, S., Rieger, K., Knochel, A. D., & Meisel, N. A.: The Impact of a Mobile 3D Printing and Making Platform on Student Awareness and Engagement.	2020	WOS
4	Harron, J. R., Emert, R., Thomas, D. M., & Campana, J.: Laying the Groundwork for STEAM: Scaling and Supporting 3D Design and Printing in Higher Education.	2022	WOS
5	Pickering, C., Fisher, E., & Ross, P.: Socio-Technical Learning: Contextualizing Undergraduate Externships to Bridge the Digital Divide	2022	WOS
6	Lou, A. J., & Jaeggi, S. M.: Reducing the prior-knowledge achievement gap by using technology-assisted guided learning in an undergraduate chemistry course.	2020	WOS
7	Wu, S. P. W., & Rau, M. A.: Effectiveness and efficiency of adding drawing prompts to an interactive educational technology when learning with visual representations.	2018	WOS
8	Andrews, M. E., Borrego, M., & Boklage, A.: Self-efficacy and belonging: The impact of a university makerspace.	2021	WOS
9	Sinha, S., Rieger, K., Knochel, A. D., & Meisel, N. A.: The Impact of a Mobile 3D Printing and Making Platform on Student Awareness and Engagement.	2020	WOS
10	Donham, C., Pohan, C., Menke, E., & Kranzfelder, P.: Increasing Student Engagement through Course Attributes, Community, and Classroom Technology: Lessons from the Pandemic.	2022	WOS
11	Gregg, N., Wolfe, G., Jones, S., Todd, R., Moon, N., & Langston, C.: STEM E-Mentoring and Community College Students with Disabilities.	2016	WOS
12	Akdere, M., Acheson, K., & Jiang, Y. L.: An examination of the effectiveness of virtual reality technology for intercultural competence development.	2021	WOS
13	Groshans, G., Mikhailova, E., Post, C., Schlautman, M., Carbajales-Dale, P., & Payne, K.: Digital Story Map Learning for STEM Disciplines.	2019	WOS
14	Bursztyn, N., Pederson, J., Shelton, B., Walker, A., & Campbell, T.: Utilizing Geo-referenced Mobile Game Technology for Universally Accessible Virtual Geology Field Trips.	2015	WOS
15	Lavicza, Z., Weinhandl, R., Prodromou, T., Andic, B., Lieban, D., Hohenwarter, M., Fenyvesi, K., Brownell, C., & Diego-Mantecon, J. M.: Developing and Evaluating Educational Innovations for STEAM Education in Rapidly Changing Digital Technology Environments.	2022	WOS
	Part III K-12		
16	Jackson, A., Godwin, A., Bartholomew, S., & Mentzer, N.: Learning from failure: A systematized review.	2022	GS
17	Hsu, Y.-C., Baldwin, S., & Ching, Y.-H.: Learning through making and maker education.	2017	GS
18	Woods, S., & Hsu, Y. C.: Making Spaces for STEM in the School Library.	2020	WOS
19	Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., Roche, J., Wong, J., Hurley, M., Bell, P., & Bevan, B.: The trouble with STEAM and why we use it anyway.	2021	WOS
20	Zhang, T. C. Y., Cummings, M., & Dulay, M. T.: An Outreach/Learning Activity for STEAM Education via the Design and 3D Printing of an Accessible Periodic Table.	2022	WOS

21	Yin, Y., Hadad, R., Tang, X. D., & Lin, Q.: Improving and Assessing Computational Thinking in Maker Activities: The Integration with Physics and Engineering Learning.	2020	WOS
22	Hammond, T. C., Bodzin, A., Anastasio, D., Holland, B., Popejoy, K., Sahagian, D., Rutzmoser, S., Carrigan, J., Farina, W.: You know you can do this, right?: developing geospatial technological pedagogical content knowledge and enhancing teachers' cartographic practices with socio-environmental science investigations.	2018	WOS
23	Fegely, A., & Tang, H. T.: Learning programming through robots: The effects of educational robotics on pre-service teachers' programming comprehension and motivation.	2022	WOS
24	Brown, A.: 3D Printing in Instructional Settings: Identifying a Curricular Hierarchy of Activities.	2015	WOS
25	Kim, N. J., & Kim, M. K.: Teacher's Perceptions of Using an Artificial Intelligence-Based Educational Tool for Scientific Writing.	2022	WOS
26	Stieben, M. E., Pressley, T. A., & Matyas, M. L.: Research experiences and online professional development increase teachers' preparedness and use of effective STEM pedagogy.	2021	WOS
27	Phelan, K. D., Syed, M., Akhter, N., Huitt, T. W., Snead, G. R., Thomas, B. R., & Yanowitz, K. L.: Bridging the Technology Divide in the COVID-19 Era: Using Virtual Outreach to Expose Middle and High School Students to Imaging Technology.	2022	WOS
28	Thompson, M. M., Wang, A., Roy, D., & Klopfer, E.: Authenticity, Interactivity, and Collaboration in VR Learning Games.	2018	WOS
29	Bernstein, D., Puttick, G., Wendell, K., Shaw, F., Danahy, E., & Cassidy, M.: Designing biomimetic robots: iterative development of an integrated technology design curriculum.	2022	WOS
30	Ziaeefard, S., Miller, M. H., Rastgaar, M., & Mahmoudian, N.: Co-robotics hands-on activities: A gateway to engineering design and STEM learning.	2017	WOS
31	Yakubova, G., Chen, B. B., & Defayette, M. A.: The Use of Technology-Based Interventions in Teaching STEM Skills to Autistic Students in K-12 Settings: A Systematic Review.	2022	WOS
	Part IV Secondary education		
32	Lee, C.-Y., Peng, L.-W., & Klemm, A.: Effective Makerspaces in STEAM Secondary Education: What Do the Professionals Think?	2021	ERIC
33	Trahan, K., Romero, S. M., Ramos, R. D., Zollars, J., & Tananis, C.: Making success: What does large-scale integration of making into a middle and high school look like?	2019	WOS
34	Schlemper, M. B., Athreya, B., Czajkowski, K., Stewart, V. C., & Shetty, S.: Teaching Spatial Thinking and Geospatial Technologies Through Citizen Mapping and Problem-Based Inquiry in Grades 7-12.	2019	WOS
35	Bowen, B. D., DeLuca, V. W., & Franzen, M. M. S.: Measuring how the degree of content knowledge determines performance outcomes in an engineering design-based simulation environment for middle school students.	2016	WOS
36	Drew, J.: Using Technology to Expand the Classroom in Time, Space, and Diversity.	2015	WOS
	Part V Youth		
37	Bowler, L., & Champagne, R.: Mindful makers: Question prompts to help guide young peoples' critical technical practices in maker spaces in libraries, museums, and community-based youth organizations.	2016	SCOPUS
38	Hsu, T. C., Abelson, H., Lao, N. T. L., & Chen, S. C.: Is It Possible for Young Students to Learn the AI-STEAM Application with Experiential Learning?	2021	WOS
39	Nugent, G., Barker, B., Grandgenett, N., & Welch, G.: Robotics Camps, Clubs, and Competitions: Results from a U.S. Robotics Project.	2016	WOS
40	McDavid, L., Parker, L. C., Li, W. L., Bessenbacher, A., Randolph, A., Harriger, A., & Harriger, B.: The effect of an in-school versus after-school delivery on students' social and motivational outcomes in a technology-based physical activity program.	2020	WOS

41	Hougham, R. J., Nutter, M., & Graham, C.: Bridging Natural and Digital Domains: Attitudes, Confidence, and Interest in Using Technology to Learn Outdoors.	2018	WOS
42	Lee, A.: An investigation of the linkage between technology-based activities and STEM major selection in 4-year postsecondary institutions in the United States: multilevel structural equation modelling.	2015	WOS
43	Rodriguez, L. S., Morzillo, A., Volin, J. C., & Campbell, T.: Conservation science and technology identity instrument: Empirically measuring STEM identities in informal science learning programs.	2020	WOS
	Part VI High School		
44	Taylor, K. H., Silvis, D., Kalir, R., Negron, A., Cramer, C., Bell, A., & Riesland, E.: Supporting public-facing education for youth: Spreading (not scaling) ways to learn data science with mobile and geospatial technologies.	2019	ERIC
45	Lindberg, L., Fields, D. A., & Kafai, Y. B.: STEAM Maker Education: Conceal/Reveal of Personal, Artistic and Computational Dimensions in High School Student Projects.	2020	WOS
46	Shanta, S., & Wells, J. G.: T/E design based learning: assessing student critical thinking and problem solving abilities.	2022	WOS
47	Yoel, S. R., Asher, D. S., Schohet, M., & Dori, Y. J.: The Effect of the FIRST Robotics Program on Its Graduates.	2020	WOS
48	Yin, Y., Khaleghi, S., Hadad, R., & Zhai, X. M.: Developing effective and accessible activities to improve and assess computational thinking and engineering learning.	2022	WOS
49	Bhuyan, J., Wu, F., Thomas, C., Koong, K., Hur, J. W., & Wang, C. H.: Aerial Drone: an Effective Tool to Teach Information Technology and Cybersecurity through Project Based Learning to Minority High School Students in the U.S.	2020	WOS
50	Okundaye, O., Natarajarathinam, M., Qiu, S. P., Kuttolamadom, M. A., Chu, S., & Quek, F.: Making STEM real: The design of a making-production model for hands-on STEM learning.	2022	WOS
51	Rau, M. A.: A Framework for Educational Technologies that Support Representational Competencies.	2017	WOS
52	Wu, J., Atit, K., Ramey, K. E., Flanagan-Hall, G. A., Vondracek, M., Jona, K., & Uttal, D. H.: Investigating Students' Learning Through Co-designing with Technology.	2021	WOS
53	Slemrod, T., Howorth, S., Wood, L., Lemmi, C., Hart, S., Cheney, D., & West, E.: A Comparison of Science Vocabulary Acquisition Using Keyword Mnemonics via Technology and Flash Cards.	2022	WOS
54	Plasman, J. S., Gottfried, M., Freeman, J., & Dougherty, S.: Promoting persistence: Can computer science career and technical education courses support educational advancement for students with learning disabilities?	2022	WOS
	Part VII Middle school		
55	Herro, D., Quigley, C., & Jacques, L. A.: Examining technology integration in middle school STEAM units.	2018	ERIC
56	Herro, D., & Quigley, C.: Innovating with STEAM in middle school classrooms: remixing education.	2016	WOS
57	Cohen, J. D., Renken, M., & Calandra, B.: Urban Middle School Students, Twenty-First Century Skills, and STEM-ICT Careers: Selected Findings from a Front-End Analysis.	2017	WOS
58	Kim, H.: Inquiry-Based Science and Technology Enrichment Program for Middle School-Aged Female Students.	2016	WOS
59	Romine, W. L., Sadler, T. D., & Wulff, E. P.: Conceptualizing Student Affect for Science and Technology at the Middle School Level: Development and Implementation of a Measure of Affect in Science and Technology (MAST).	2017	WOS
60	Campbell, T., Zuwallack, R., Longhurst, M., Shelton, B. E., & Wolf, P. G.: An Examination of the Changes in Science Teaching Orientations and Technology-Enhanced Tools for Student Learning in the Context of Professional Development.	2014	WOS
61	Lin, Q., Yin, Y., Tang, X. D., Hadad, R., & Zhai, X. M.: Assessing learning in technology-rich maker activities: A systematic review of empirical research.	2020	WOS

62	Ntemngwa, C., & Oliver, J. S.: The Implementation of Integrated Science Technology, Engineering and Mathematics (STEM) Instruction using Robotics in the Middle School Science Classroom.	2018	WOS
63	Hollman, A. K., Hollman, T. J., Shimerdla, F., Bice, M. R., & Adkins, M.: Information technology pathways in education: Interventions with middle school students.	2019	WOS
64	Wolf, V., Hsiao, V., Rodriguez, B., Min, A., Mayorga, J., & Ashcroft, J.: utilization of Remote Access Electron Microscopes to Enhance Technology Education and Foster STEM Interest in Preteen Students.	2022	WOS
	Part VIII Elementary school		
65	Ramey, K. E., & Stevens, R.: Interest development and learning in choice-based, in-school, making activities: The case of a 3D printer.	2019	SCOPUS
66	Ramey, K. E., Stevens, R., & Uttal, D. H.: In-FUSE-ing STEAM learning with spatial reasoning: Distributed spatial sensemaking in school-based making activities.	2020	ERIC
67	Cook, K., Bush, S., Cox, R., & Edelen, D.: Development of elementary teachers' science, technology, engineering, arts, and mathematics planning practices.	2020	WOS
68	Barnes, J., FakhrHosseini, S. M., Vasey, E., Park, C. H., & Jeon, M.: Child–Robot Theater: Engaging Elementary Students in Informal STEAM Education Using Robots.	2020	WOS
69	Yannier, N., Crowley, K., Do, Y., Hudson, S. E., & Koedinger, K. R.: Intelligent science exhibits: Transforming hands-on exhibits into mixed-reality learning experiences.	2022	WOS
70	Kim, Y. R., Park, M. S., & Tjoe, H.: Discovering Concepts of Geometry through Robotics Coding Activities.	2021	WOS
71	Searle, K. A., Tofel-Grehl, C., Hawkman, A. M., Suarez, M. I., & MacDonald, B. L.: A case study of whiteness at work in an elementary classroom.	2022	WOS
72	Hughes, C. E., Dieker, L. A., Glavey, E. M., Hines, R. A., Wilkins, I., Ingraham, K., Bukaty, C. A., Ali, K., Shah, S. C., Murphy, J., & Taylor, M. S.: RAISE: Robotics & AI to improve STEM and social skills for elementary school students.	2022	WOS
73	Vallera, F. L., & Bodzin, A. M.: Integrating STEM with AgLIT (Agricultural Literacy Through Innovative Technology): The Efficacy of a Project-Based Curriculum for Upper-Primary Students.	2020	WOS
74	Van Eck, R. N., Guy, M., Young, T., Winger, A. T., & Brewster, S.: Project NEO: A Video Game to Promote STEM Competency for Preservice Elementary Teachers.	2015	WOS
75	Huang, K. T., Ball, C., Cotten, S. R., & O'Neal, L. J.: Effective Experiences: A Social Cognitive Analysis of Young Students' Technology Self-Efficacy and STEM Attitudes.	2020	WOS
	Part IX Early childhood education		
76	Sullivan, A., & Bers, M. U.: Robotics in the early childhood classroom: learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade.	2016	WOS
77	Sullivan, A., & Bers, M. U.: Investigating the use of robotics to increase girls' interest in engineering during early elementary school.	2019	WOS
78	Taylor, M. S., Vasquez, E., & Donehower, C.: Computer Programming with Early Elementary Students with Down Syndrome.	2017	WOS
79	Elkin, M., Sullivan, A., & Bers, M. U.: Implementing a Robotics Curriculum in an Early Childhood Montessori Classroom.	2014	WOS
80	Hamilton, M., Clarke-Midura, J., Shumway, J. F., & Lee, V. R.: An Emerging Technology Report on Computational Toys in Early Childhood.	2020	WOS
81	Pila, S., Lauricella, A. R., Piper, A. M., & Wartella, E.: Preschool teachers' perspectives on (haptic) technology in the classroom.	2022	WOS
	Part X Others		
82	Taljaard, J.: A review of multi-sensory technologies in a science, technology, engineering, arts and mathematics (STEAM) classroom.	2016	GS

Note: GS, Google Scholar; WOS, Web of Science