International Journal of Essential Competencies in Education
https://journal-center.litpam.com/index.php/ijece/index

Dec. 2023 Vol. 2, No. 2
e-ISSN: 2962-2131
pp. 177-196

Surmounting Obstacles in STEM Education: An In-depth Analysis of Literature Paving the Way for Proficient Pedagogy in STEM Learning

Fernando Salvetti [1], Khaerul Rijal [2]*, Isaac Owusu-Darko [3], Saiful Prayogi [4]

1. Centro Studi Logos, Turin, Italy
2. The University of Sheffield, Sheffield, South Yorkshire, United Kingdom
3. Department of Mathematics Education, Valley View University, Techiman 183, Ghana
4. Department of Science Education, Mandalika University of Education, Mataram, Indonesia

*Correspondence: KRIjal1@sheffield.ac.uk

Article Info

Article History
Received: November 2023;
Revised: November 2023;
Published: December 2023

Keywords
STEM education;
Effective pedagogy;
Review of the literature;
Challenges;
Opportunities

Abstract

The modern educational system has recognized the significance of STEM as a vital component of students' preparation for a promising future. Consequently, there is a need for comprehensive research in STEM education, encompassing an understanding of its context, challenges, and strategies to overcome these obstacles. Ongoing research continues to focus on developing coherent studies in this area, particularly emphasizing effective STEM pedagogy, which has proven to positively impact students' learning outcomes. However, despite its potential, STEM education faces several challenges that could impede its progress. In the scope of this study, a thorough examination revealed at least six key challenges confronting, these challenges encompass: pedagogical challenges, curriculum-related issues, structural complexities, student apprehensions, assessment concerns, and the critical need for teacher support. These challenges, along with proposed solutions, are discussed in-depth in this article. It is worth noting that pedagogical challenges hold paramount importance, as teachers play a pivotal role in implementing successful STEM education in schools. As such, this article delves into various effective pedagogical aspects that can facilitate the advancement of STEM education and foster enhanced learning experiences for students. Several key aspects contribute to effective pedagogy in STEM education and learning, including: (a) cultivating an innovative learning environment that nurtures inquiry, experimentation, and critical thinking; (b) utilizing a diverse range of authentic learning methods and relevant educational resources; (c) facilitating a collaborative learning environment that encourages teamwork and knowledge sharing; (d) creating an inclusive learning environment that accommodates the diverse needs of students; and (e) encouraging continuous reflection on and improvement of teaching practices to optimize learning outcomes.

https://doi.org/10.36312/ijece.v2i2.1614

How to Cite

Salvetti, F., Rijal, K., Owusu-Darko, I., & Prayogi, S. (2023). Surmounting Obstacles in STEM Education: An In-depth Analysis of Literature Paving the Way for Proficient Pedagogy in STEM Learning. *International Journal of Essential Competencies in Education*, *2*(2), 177–196. https://doi.org/10.36312/ijece.v2i2.1614

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education is an interdisciplinary approach to learning that integrates science, technology, engineering, and

mathematics, with the primary goal of equipping students with the ability to address real-world challenges. By fostering a connection between various scientific disciplines, STEM education empowers students to develop the knowledge and skills necessary to tackle a wide array of 21st-century challenges successfully. This emphasis on STEM education has led it to become a crucial yardstick for measuring the effectiveness of human resource development in educational systems worldwide, as it directly correlates with a country's global competitiveness (Kayan-Fadlelmula et al., 2022). Furthermore, STEM education plays a pivotal role in building human capacity (Miller-Idriss & Hanauer, 2011), and acts as a potential catalyst for students to pursue careers in STEM fields later in life (Lee et al., 2019; Margot & Kettler, 2019). By instilling a sense of curiosity, creativity, and problem-solving ability, STEM education nurtures students' interest in science, technology, engineering, and mathematics, thus encouraging their continued participation and contribution to these fields in the future. Its impact goes beyond traditional academic settings, as it prepares individuals to thrive in a rapidly evolving world where innovation and adaptability are paramount.

In modern education, there has been a notable surge in the emphasis on STEM as a means of preparing students for a promising future. This has led numerous educational systems to recognize the significance of incorporating STEM into their curricula (Al Salami et al., 2017; Bagiati & Evangelou, 2015). Consequently, various approaches have been adopted to integrate STEM education effectively into regular teaching methods, highlighting its vital role in the overall learning system (Holmlund et al., 2018; Li et al., 2019). The integration of STEM can take place at different levels: firstly, the disciplinary level, where concepts from each discipline are taught separately; secondly, the multi-disciplinary level, in which concepts from individual disciplines are learned independently but within the context of the same theme; thirdly, the interdisciplinary level, where concepts from two or more closely related disciplines are combined to enhance knowledge and skills; and finally, the transdisciplinary level, which involves the application of knowledge and skills from multiple disciplines to address real-world problems and engage in projects, enriching the overall learning experience (Leung, 2020).

STEM has a long history of being explored both as a separate discipline and in multidisciplinary contexts in the past. However, its development has led to a significant shift towards interdisciplinary and transdisciplinary integration, particularly in developed countries, giving rise to what is now commonly known as interdisciplinary STEM education. This approach has emerged to address a wide range of authentic challenges that demand solutions from various interdisciplinary fields. For instance, environmental pollution and waste processing issues necessitate insights from disciplines such as biological sciences, chemical sciences, and engineering. Weather forecasting, on the other hand, relies on interdisciplinary knowledge from biological sciences, chemical sciences, physical sciences, and technology. Matters concerning radiation technology draw upon expertise from all scientific domains (biology, chemistry, and physics), along with engineering and advanced technology. Even in the realm of current robotic system automation, successful implementations stem from the integration of interdisciplinary knowledge encompassing technology, engineering, and mathematics. The need for integrative knowledge in the STEM field persists across numerous contexts and applications. Overall, the evolution of STEM education towards interdisciplinary approaches has paved the way for more comprehensive and effective problem-solving, leading to innovative solutions across various scientific and technological challenges.

Up to this point, the progress of STEM education has been acknowledged in several developed countries, like the United States, where it is seen as a crucial factor for future

industrial resource development (Lee et al., 2019). This progress is attributed to educational reforms that focus on fostering complex engineering and technology skills in students and promoting their active involvement in a knowledge-based modern economy (Börner et al., 2018; van Laar et al., 2017). However, it should be noted that challenges persist for educators in implementing STEM education, as highlighted in various reports (Ryu et al., 2019). These challenges are particularly evident in developing countries across Asia (Lee et al., 2019). Additionally, the limited availability of STEM integration models in the existing literature creates further obstacles for teachers attempting to effectively implement integrated STEM education in schools (Smith et al., 2022). Recognizing the importance of addressing these issues, Lee et al. (2019) advocate for more research to be conducted on the implementation of STEM education by teachers in developing countries, where knowledge about effective implementation and strategies for improving effectiveness remains limited.

The exploration of STEM pedagogy has gained significant importance in order to gain a comprehensive understanding of its effectiveness and address the challenges in STEM learning. Thus, in this particular research, a specific focus is given to defining the terminology of STEM education within the context of STEM learning. The primary objectives of this study are as follows (1) to investigate the trends in research concerning the challenges and opportunities faced in STEM education; (2) to examine the current challenges and opportunities in STEM education; (3) to propose solution approaches to tackle the challenges encountered in STEM education and learning; and (4) to outline the characteristics of effective STEM pedagogy.

METHOD

In order to accomplish the objectives of this research, an extensive examination of existing literature in the domain of STEM education and learning was carried out, with a particular focus on employing bibliometric analysis. This analysis not only serves as a foundation for assessing the prevailing challenges in STEM education and learning but also involves an exploration of various approaches to overcome these obstacles and elucidates the principles of effective STEM pedagogy. The methodology for the bibliometric analysis was adapted from a prior study by Wirzal et al. (2022), and it constitutes a comprehensive review of relevant literature centered around the theme of "challenges and opportunities in STEM education."

This literature review encompasses a wide array of sources, including scholarly studies, documents, and specialized databases, thus adding to its depth and credibility. Essentially, this research also qualifies as a meta-analysis, where the collective findings from multiple studies are analyzed and synthesized to gain a comprehensive perspective on the study matter. By undertaking this meticulous approach, the study seeks to shed light on the pressing issues within STEM education and learning while presenting potential solutions and effective pedagogical methods to enhance the overall learning experience in STEM disciplines.

The bibliometric analysis was performed utilizing the SCOPUS database (https://www.scopus.com/) as the primary information source, which is renowned for its unparalleled accuracy and is widely regarded as one of the most reliable repositories of scholarly data globally. Notably, the SCOPUS database assesses the quality of articles within a publisher's purview, ensuring the inclusion of only top-notch publications. The database boasts comprehensive features that enable users to meticulously explore high-quality articles based on various criteria, such as authorship, titles, publication years, publishers, citation counts, and other metric data, ensuring precise and insightful analyses.

On May 1st, 2023, a bibliometric analysis was undertaken using the SCOPUS database, employing relevant English keywords and search terms related to the subject of the study. The selection of SCOPUS as the database was carefully considered to ensure comprehensive coverage of materials pertinent to the research topic, "challenges and opportunities in STEM education" ("TITLE-ABS-KEY": 'Challenges' AND 'and' AND 'opportunities' AND 'in' AND 'STEM' AND 'education'). Notably, this search was not restricted by any specific year, subject area, document type, or source, allowing for a comprehensive examination of available data.

The screening process is carried out to ensure that the documents being analyzed are closely related to the themes in this study. The screening process is as presented in Figure 1.

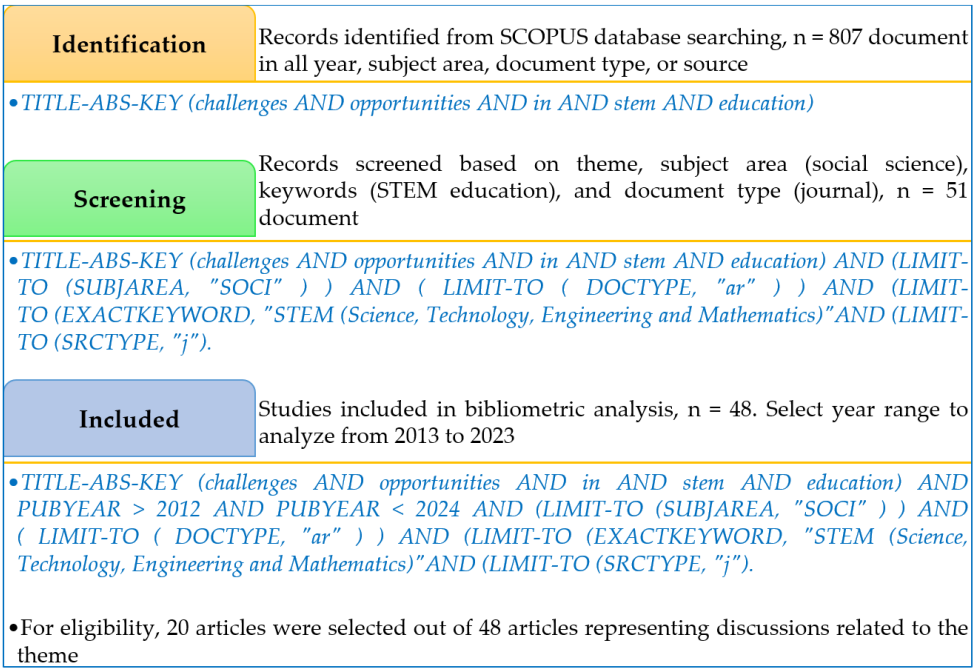


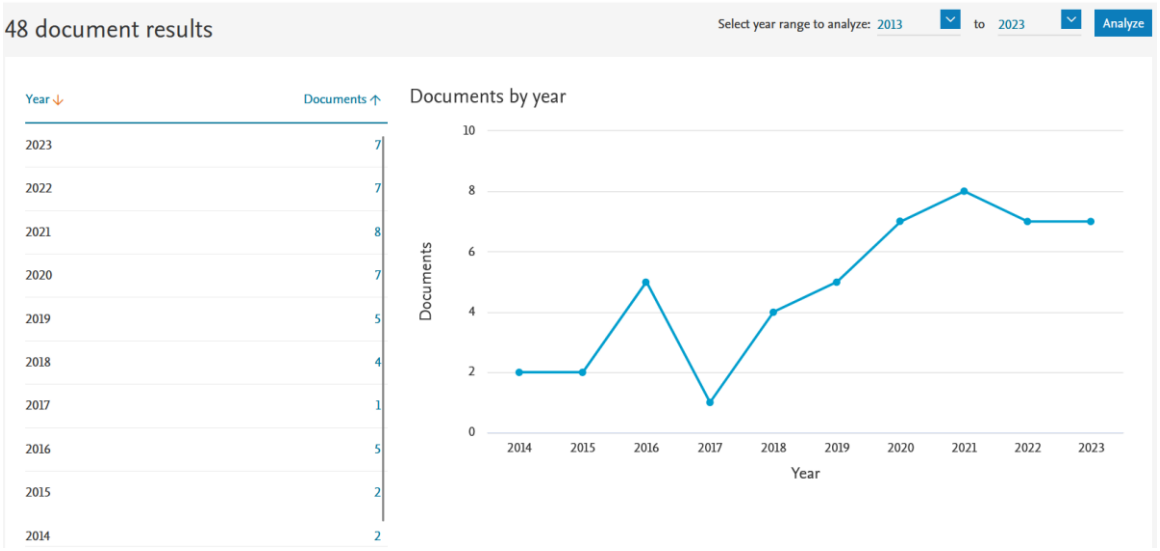
Figure 1. The process of screening documents according to the theme "challenges and opportunities in STEM education."

Throughout the process, each search result was meticulously documented and curated in a (.ris)/(.csv) file to maintain a systematic record. Additionally, visual representations of the data were captured through screen printing (prt-scr) from the SCOPUS database, facilitating a detailed analysis and constructive discussions. The bibliometric analysis yielded valuable insights, forming the foundation for exploring the current challenges and opportunities in STEM education and learning, as well as identifying potential approaches to overcome these obstacles and enhance effective STEM pedagogy. By drawing comparisons with other pertinent literature, the results served as a robust starting point for advancing our understanding of the complex landscape of STEM-based education challenges and solutions.

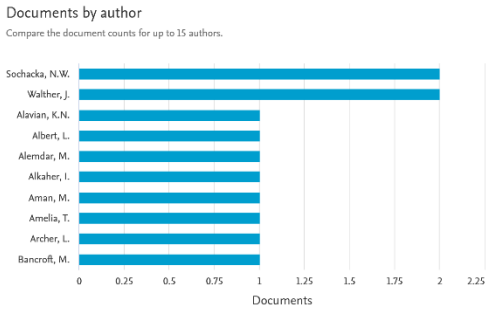
RESULTS AND DISCUSSION

Investigate the trends in research concerning the challenges and opportunities faced in STEM education

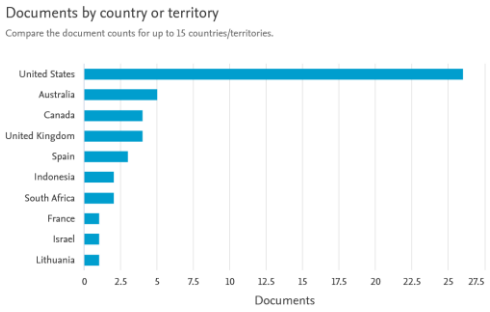
An in-depth investigation of the topic "challenges and opportunities in STEM education" was conducted, encompassing a comprehensive review of the existing literature. The analysis comprised various study sources, documents, and data from SCOPUS, spanning a period of ten years, from 2013 to 2023. The research yielded a total of forty-eight relevant documents during this time frame, as depicted in Figure 2.



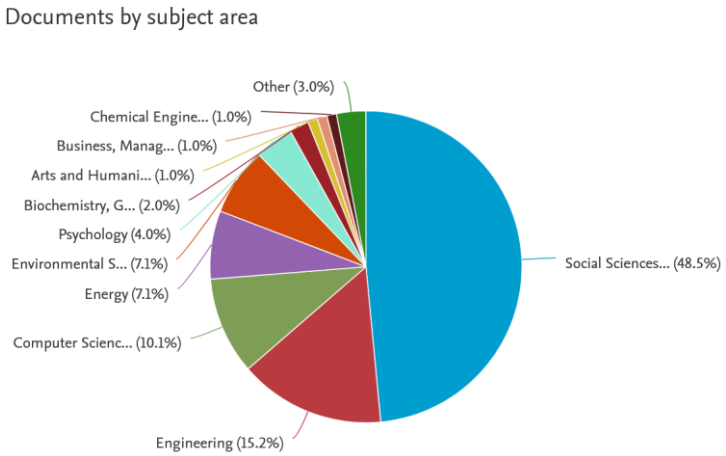
(a)



(b)



(c)



(d)

Figure 2. The findings from the SCOPUS data analysis over the year of 2013 to 2023: (a) documents by year; (b) documents by author; (c) documents by country or territory; and (d) documents by subject area.

For eligibility, 20 articles were selected out of 48 articles representing discussions related to the them in the last ten years (2013 to 2023). The scope of this subject area not only encompasses STEM fields but also extends to intersecting domains like social science, environmental science, psychology, and others. To access the list of documents specifically related to the theme of "challenges and opportunities in STEM education" kindly refer to Table 1, which can be found on the SCOPUS database https://www.scopus.com/.

Table 1. Documents related to the theme "challenges and opportunities in STEM education"

No	Article Title	Author(s) and Year	Jornal Abbr. and Article DOI
1	Challenges and Opportunities: Asian Women in Science, Technology, Engineering, and Mathematics.	(Varma et al., 2023)	*American Behav Scie*, doi: 10.1177/00027642221078509
2	Out-of-the-Box Learning: Digital Escape Rooms as a Metaphor for Breaking Down Barriers in STEM Education.	(Sidekerskienė & Damaševičius, 2023)	*Sustainability*, doi: 10.3390/su15097393
3	Maker culture and its potential for STEM education.	(Tabarés & Boni, 2023)	*Int J Technol Des Educ*, doi: 10.1007/s10798-021-09725-y
4	Effect of design-based learning on achievement in K-12 education: A meta analysis.	(Delen & Sen, 2023)	*J Res Sci Teach*, doi: 10.1002/tea.21800
5	Research Trend of Big Data in Education During the Last 10 Years.	(Prahani et al., 2023)	*Int J Eme Tech Learn*, doi: 10.3991/ijet.v18i10.38453
6	Building motivationally supportive course-based research experiences for undergraduates: a self-determination theory perspective.	(Scogin et al., 2023)	*High Edu Ped*, doi: 10.1080/23752696.2023.2165528
7	Study of computer attitudes in STEM problem-solving for students with disabilities.	(Du & Lyublinskaya, 2023)	*Comp Applic In Engineering*, doi: 10.1002/cae.22574
8	Engaging Government-Industry-University Partnerships to Further Gender Equity in STEM Workforce Education Through Technology and Information System Learning Tools.	(Knestis et al., 2022)	*Journal of Information Systems Education, doi: -*
9	Broadening the Pool of Precollege Engineering Teachers: The Path Experienced by a Music Teacher.	(Dalal et al., 2022)	*IEEE Trans Edu*, doi: 10.1109/TE.2022.3141984
10	Sustainability and Justice: Challenges and Opportunities for an Open STEM Education.	(Diaz Eaton et al., 2022)	*LSE*, doi: 10.1187/cbe.20-08-0180
11	Introducing and Evaluating the Effective Inclusion of Gender Dimension in STEM Higher Education.	(Peña et al., 2021)	*Sustainability*, doi: 10.3390/su13094994

No	Article Title	Author(s) and Year	Jornal Abbr. and Article DOI
12	Determinants of mobile learning acceptance for STEM education in rural areas.	(Mutambara & Bayaga, 2021)	*Comp & Edu*, doi: 10.1016/j.compedu.2020.104010
13	An analytical view on STEM education and outcomes: Examples of the social gap and gender disparity in Vietnam.	(Ho et al., 2020)	*Children & Youth Ser Rev*, doi: 10.1016/j.childyouth.2020.105650
14	Experiences, activities, and personal characteristics as predictors of engagement in STEM-focused summer programs.	(Schmidt et al., 2020)	*J Res Sci Teach*, doi: 10.1002/tea.21630
15	Pedagogies for employability: understanding the needs of STEM students through a new approach to employability development.	(Bennett et al., 2020)	*Hig Edu Ped*, doi: 10.1080/23752696.2020.1847162
16	Fixing STEM Workforce and Teacher Shortages: How Goal Congruity Can Inform Individuals and Institutions.	(Diekman & Benson-Greenwald, 2018)	*Pol Ins Behav & Brain Sci*, doi: 10.1177/2372732217747889
17	STEM Faculty as Learners in Pedagogical Reform and the Role of Research Articles as Professional Development Opportunities.	(Mulnix, 2016)	*LSE*, doi: 10.1187/cbe.15-12-0251
18	Engaging voices: Methods for studying STEM education at Historically Black Colleges and Universities (HBCUs).	(Gasman & Nguyen, 2016)	*JME*, doi: 10.1108/JME-01-2016-0011
19	Learning Together: A Collaborative Autoethnographic Exploration of STEAM (STEM + the Arts) Education.	(Sochacka et al., 2016)	*J Eng Educ*, doi: 10.1002/jee.20112
20	Latino parents' educational values and STEM beliefs.	(Hernandez et al., 2016)	*JME*, doi: 10.1108/JME-12-2015-0042

Expanding on the examination of the articles presented in Table 1, it was observed that nearly all of the research pertaining to STEM education and learning acknowledges the significance of effective STEM pedagogy in fostering knowledge. The challenges and opportunities in STEM education form a dynamic landscape that demands a comprehensive approach. By addressing issues of STEM education, we can bridge the gaps and harness the potential of STEM education. Empowering students with the right skills and knowledge not only prepares them for the future but also cultivates a generation of thinkers and problem-solvers capable of shaping a better world through innovation and excellence. Nevertheless, while conducting a thorough review of various literature sources, certain challenges in STEM

education and learning were also discovered. These challenges are deemed crucial to the present study, and thus, strategies to address each of these obstacles are extensively discussed.

Examine the current challenges in STEM education and learning

STEM education has been widely embraced by numerous countries as an essential component of modern education. Nonetheless, its adoption has introduced a set of challenges, mainly because it departs from the traditional subject-based paradigm. As a consequence, researchers have directed their efforts towards comprehensively identifying the barriers that hinder the effective implementation of STEM education.

In the scope of this study, a thorough examination revealed at least six key challenges confronting STEM education and learning. These challenges encompass pedagogical challenges, curriculum-related issues, structural complexities, student apprehensions, assessment concerns, and the critical need for teacher support. Notably, these findings resonate with previous research conducted by Margot and Kettler (2019) and have been further corroborated by investigations carried out in diverse contexts by scholars such as Bagiati and Evangelou (2015), Dong et al. (2020), Holstein and Keene (2013), and Shernoff et al. (2017). To shed light on these barriers, the study draws upon relevant literature and builds upon the insights provided by earlier research. Moreover, the paper offers valuable recommendations and potential solutions to surmount the challenges and obstacles that impede the successful implementation of STEM education.

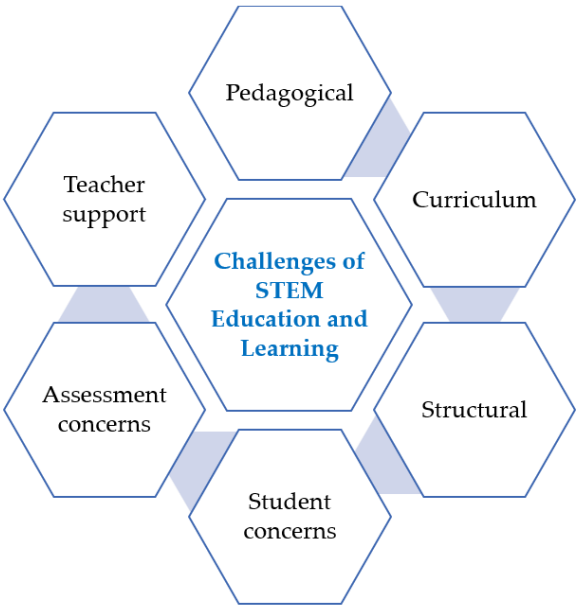


Figure 3. Six key challenges confronting STEM education and learning

In conclusion, the widespread integration of STEM education in various educational systems has not been without its difficulties. The unconventional nature of STEM compared to traditional subject-based teaching has led to the emergence of several impediments. Through a meticulous examination of the subject, this study has identified six main challenges encompassing pedagogy, curriculum, structure, student perspectives, assessment practices, and the crucial aspect of teacher support. These findings find alignment with previous research, underlining the significance and universality of these challenges. In light of these barriers, the study not only delves into relevant past works but also proposes actionable recommendations to effectively address and overcome these challenges, thereby paving the way for a more successful and robust implementation of STEM education.

Pedagogical

Teachers often find the concept of integrating STEM education into their current teaching methods daunting, leading them to question their readiness to implement STEM pedagogy. STEM education necessitates an instructional approach that emphasizes student leadership in the learning process, requiring a new pedagogical framework altogether (Lesseig et al., 2016; M.-H. Park et al., 2017). Furthermore, aligning their teaching methods with the STEM curriculum is a concern shared by teachers, as highlighted by Bagiati and Evangelou (2015) and Holstein and Keene (2013).

Another major concern is addressing the diverse needs of students, as pointed out by Herro and Quigley (2017). Additionally, Dare et al. (2014) suggest that teachers may fear that integrating STEM could lead to neglecting essential content concepts in science education. These challenges arise due to the interdisciplinary nature of STEM, necessitating teachers to adapt their beliefs and knowledge about STEM (Dong et al., 2020). In order to effectively address these challenges, STEM instructors must comprehend and establish a suitable pedagogical infrastructure for STEM teaching. It is crucial to overcome these obstacles to foster successful STEM pedagogy.

Curriculum

Developing a comprehensive STEM curriculum poses a challenge due to its integrated nature. Interdisciplinary design is crucial for effective STEM teaching within the curriculum. Educators often encounter the complexity of creating a flexible STEM curriculum, which can be perceived as rigid and inflexible by instructors. Moreover, integrating different specific domains within STEM, such as Biology and Geometry, presents additional difficulties (Asghar et al., 2012). This integration can result in miscommunication of knowledge between teachers and their respective domains, leading to instructor anxiety when implementing the STEM curriculum (Asghar et al., 2012; Bell, 2016; EL-Deghaidy et al., 2017).

To overcome these challenges and build effective STEM curricula, educators must recognize the interdisciplinary nature of STEM, acquire knowledge of integrating studies across STEM fields, and understand the content in various STEM areas (Shernoff et al., 2017). Emphasizing these aspects can offer opportunities for success in developing well-rounded STEM educational programs.

Structural

The conventional organizational frameworks found in educational institutions like schools and universities can pose significant obstacles to the adoption of innovative STEM education practices, as highlighted in various research studies (Dong et al., 2020; Margot & Kettler, 2019; Shernoff et al., 2017). The specific policies and structure of these institutions can significantly influence the successful implementation and advancement of STEM education initiatives. Unlike other academic disciplines, STEM learning typically demands more time and resources. However, when school policies restrict the allocation of time for STEM learning, it can have detrimental effects on the effective planning and execution of STEM education programs. Furthermore, frequent changes to the curriculum driven by policy decisions can create additional challenges and burden teachers in devising effective STEM education strategies (Herro & Quigley, 2017).

Several research studies have also explored other structural barriers, including administrative hurdles (Clark & Andrews, 2010), as well as inadequate resources and infrastructure support (Wang et al., 2011). These obstacles collectively contribute to the complexity of promoting and sustaining high-quality STEM education in educational institutions.

Student concerns

The integration of STEM education encounters various obstacles, particularly regarding student capabilities. Teachers often express concerns about maintaining active student engagement in STEM learning, which can hinder the overall success of STEM education. Another critical factor is the impact of student motivation on their learning outcomes in STEM subjects (Aeschlimann et al., 2016). Some studies (Al Salami et al., 2017; Van Haneghan et al., 2015) indicate that teachers may underestimate their students' problem-solving abilities in STEM based on their teaching experiences, leading to a potential decrease in student motivation. This issue is particularly pronounced in rural areas, where students may face lower performance levels. Furthermore, addressing these diverse student needs and adapting STEM lesson plans accordingly presents a formidable challenge for educators (Goodpaster et al., 2012). Consequently, these concerns have a significant impact on how teachers approach and implement STEM learning in their classrooms (Holstein & Keene, 2013).

Assessment concerns

Teachers encounter considerable obstacles when attempting to incorporate STEM integration into their classrooms. These challenges are primarily associated with the absence of dependable assessment instruments, insufficient planning and execution time for assessments, and a lack of comprehensive STEM knowledge among educators (Margot & Kettler, 2019). One of the major contentions raised by teachers is the dearth of standardized evaluation methods specifically tailored for STEM programs. This dearth of appropriate assessment tools complicates the task of accurately gauging students' performance in STEM subjects (Nadelson & Seifert, 2013). As a result, measuring the true extent of students' grasp of STEM concepts becomes a formidable undertaking. Furthermore, the issue of whether to conduct individual or group assessments has become a subject of intense debate among educators (Herro & Quigley, 2017). Each approach has its advantages and drawbacks, making it challenging for teachers to determine which method is more effective in evaluating students' proficiency in STEM-related topics.

In conclusion, the effective implementation of STEM integration in classrooms is hampered by various impediments. These challenges include the absence of reliable assessment tools that align with STEM objectives, the limited time available for planning and executing assessments, and teachers' own inadequacies in possessing comprehensive STEM knowledge. Additionally, the absence of standard evaluation methods designed explicitly for STEM programs and the ongoing debate over the merits of individual versus group assessments further compound the complexities of accurately assessing students' performance in STEM disciplines. Addressing these challenges is crucial to creating an optimal learning environment that fosters students' growth and success in STEM education.

Teacher support

The teacher plays a central role in the implementation of policies for STEM education and learning. They carry the responsibility for various aspects of STEM education, making their support crucial in this context. However, managing the additional workload associated with STEM education can be challenging for teachers. This includes tasks such as developing effective pedagogical frameworks for STEM, integrating STEM curricula into their plans, preparing students to excel in STEM subjects, creating suitable assessment tools, and more (Margot & Kettler, 2019). Teachers often find themselves needing to invest extra time in STEM education.

One significant challenge faced by educators when implementing STEM education is the shortage of time, particularly when they have to fulfill other administrative demands (H.

Park et al., 2016). Additionally, some teachers feel that their knowledge of STEM subjects is insufficient, which can impact the success of STEM education provision. Studies have shown that pre-service teacher training programs often do not adequately prepare teachers for teaching STEM (Al Salami et al., 2017; Hsu, 2021; Nadelson & Seifert, 2013). Moreover, teachers express concern about the high expectations placed upon them by schools and policymakers regarding student STEM learning outcomes. Although teachers understand the importance of integrating STEM subjects into the curriculum, they lack confidence in effectively delivering STEM lessons, potentially affecting the overall effectiveness of STEM teaching.

Propose solution approaches to tackle the challenges encountered in STEM education and learning

As of now, the existing body of literature on overcoming challenges in STEM education and learning appears limited. Nevertheless, through a comprehensive analysis of relevant studies, we have identified several potential approaches to tackle these obstacles, as outlined in Table 2.

Table 2. The solution approaches to tackle the challenges encountered in STEM education and learning

Challenges		Propose solution approaches
Pedagogical	• The unpreparedness of educators in adopting STEM pedagogy can be attributed to their limited comprehension of the most effective ways to implement it in the classroom.	• Each educator in the STEM field must possess a comprehensive understanding of and construct an appropriate and efficient pedagogical framework for facilitating STEM education.
Curriculum	• The development of STEM curriculum encounters challenges due to its interdisciplinary nature, particularly in the integration of various specific content or domains within the field.	• Comprehending the interdisciplinary essence of the STEM curriculum, having the ability to merge various fields of study within STEM, and possessing a deep understanding of the content in these areas can open doors to success in crafting a robust and efficient STEM curriculum.
Structural	• The conventional organizational structures and policies within educational institutions often fail to place sufficient emphasis on the advancement of STEM education. Consequently, there is a notable absence of adequate resource allocation to cater to the requirements and growth of STEM disciplines.	• Generally, educational institutions have the autonomy to regulate their own institutional structures. However, for the purpose of enhancing STEM education, it is important to incorporate government regulations into interventions. By doing so, we can foster the growth and advancement of STEM education within schools.

Challenges		Propose solution approaches
Student concerns	• The level of enthusiasm among students for STEM subjects is noticeably limited, leading to a discernible influence on their overall performance in STEM education.	• The topic at hand concerns the organization of STEM education, incorporating a proficient pedagogical approach to foster motivation in students engaging with STEM subjects.
Assessment concerns	• At present, a universally accepted evaluation approach for STEM programs is yet to be established, presenting a formidable undertaking for educators to effectively gauge the achievements of their STEM students.	• A robust evaluation approach is crucial for STEM programs, specifically aligned with the approved curriculum. The field of STEM demands the incorporation of authentic assessment techniques to gauge student performance effectively.
Teacher support	• The limited familiarity of educators with the STEM field, combined with the added burden on their responsibilities, impedes their ability to fully embrace and facilitate the integration of STEM education.	• The implementation of teacher training programs is crucial for effectively instructing STEM subjects, aiming to equip every educator with a comprehensive understanding of the respective STEM domain..

While teachers play a crucial role in the implementation of STEM education policies, the responsibility for addressing challenges extends beyond them. The issues pertaining to curriculum seem to involve all stakeholders in STEM education, such as policy makers, schools, and teachers. Structural challenges, on the other hand, squarely fall under the responsibility of schools and governments, who should actively promote the growth of STEM education within educational institutions. This includes addressing concerns related to assessments in line with the curriculum and providing adequate support to teachers.

Consequently, teachers shoulder a significant burden in establishing an effective pedagogical framework for STEM education and fostering a conducive learning environment. By doing so, they can effectively address student concerns and contribute to problem-solving initiatives.

The characteristics of effective STEM pedagogy

Developing effective STEM pedagogy presents an epistemic challenge when transitioning from one discipline to another within the STEM scope. This challenge arises due to the unique practices inherent in each STEM field, making modification difficult (Leung, 2020). Therefore, to address this issue, it becomes essential to establish a comprehensive learning framework that embraces the interdisciplinary nature of STEM. Such a framework should focus on nurturing students' knowledge, skills, attitudes, and fostering positive learning outcomes across different STEM disciplines.

The significance of effective pedagogy in STEM education cannot be overstated. STEM subjects are deeply integrated across various disciplines, underscoring the importance of cultivating STEM competencies. By employing effective pedagogy, students can gain a profound understanding of the concepts, methods, and practices specific to STEM fields,

equipping them to tackle real-world challenges with confidence. Several key aspects contribute to effective pedagogy in STEM education and learning, including:

a) Cultivating an innovative learning environment that nurtures inquiry, experimentation, and critical thinking.
b) Utilizing a diverse range of authentic learning methods and relevant educational resources.
c) Facilitating a collaborative learning environment that encourages teamwork and knowledge sharing.
d) Creating an inclusive learning environment that accommodates the diverse needs of students.
e) Encouraging continuous reflection on and improvement of teaching practices to optimize learning outcomes.

In summary, a well-structured and effective pedagogical approach is vital for unlocking the full potential of STEM education, fostering interdisciplinary connections, and preparing students to tackle real-world challenges in the dynamic fields of STEM.

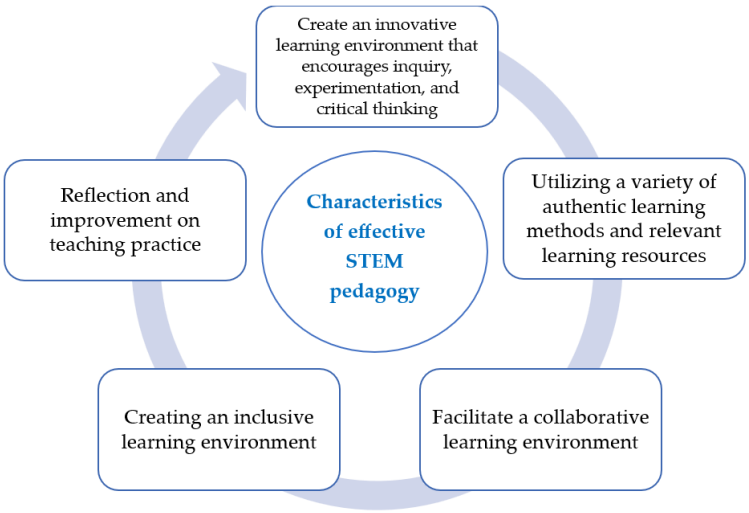


Figure 4. The characteristics of effective STEM pedagogy

Effective pedagogy in STEM education involves fostering an innovative and engaging learning environment that promotes inquiry, experimentation, and critical thinking among students. By encouraging students to ask questions and providing opportunities for exploration, teachers empower them to become active learners responsible for their own educational journey (Ryoo & Winkelmann, 2021). This approach to teaching not only allows students to develop a deeper understanding of STEM concepts but also enhances their chances of success in STEM learning.

Innovative learning is characterized by processes that encourage inquiry and experimentation, leading to activities that foster critical thinking (Wahyudi et al., 2019). Scientific literacy achieved through exploration, experimentation, and inquiry has been shown to improve students' critical thinking performance in STEM subjects (Bilad, Doyan, et al., 2022). Moreover, inquiry-based learning has been found effective in guiding STEM education both in separate and integrated disciplines. In integrated STEM, technology serves as a bridge to integrate science, engineering, and mathematics teaching, resulting in improved scientific skills and learning motivation (Wang et al., 2015). Even in remote learning, the

presence of technology facilitates the acquisition of critical thinking skills among STEM students (Bilad, Anwar, et al., 2022).

Secondly, effective pedagogy in STEM demands the use of authentic learning methods and relevant resources. Teachers must adopt various authentic problem-solving approaches such as problem-based learning (PBL), project-based learning (PjBL), and case-based learning (CBL). PBL, in particular, has proven to be a successful model in building students' knowledge and skills, metacognitive reasoning, motivation, and collaboration in STEM education (Biazus & Mahtari, 2022; Ekayanti et al., 2022; Hidayat & Evendi, 2022). Similarly, PjBL and CBL are valuable tools to develop problem-solving abilities and enhance student motivation and interest in learning (Coufal, 2022; Domenici, 2022; Oyewo et al., 2022). Teachers should also incorporate multimedia, simulations, and real-world applications to make STEM subjects more accessible to students. Technological resources play a crucial role in bridging the gap between students and abstract STEM content such as cells, sound waves, and electric current.

Thirdly, effective pedagogy in STEM education requires the facilitation of a collaborative learning environment. STEM professionals often work in teams, and collaborative learning helps students develop essential skills such as teamwork, communication, and problem-solving. Encouraging students to work together, share ideas, and actively participate in group discussions promotes positive collaboration in STEM learning. Studies have demonstrated that collaborative work enhances STEM students' cognitive performance (Lange et al., 2021) and teamwork skills, leading to the production of higher-quality products (Kilty & Burrows, 2022).

Fourth, effective pedagogy entails creating a culturally responsive and inclusive learning environment that caters to diverse learners. STEM education must be accessible and equitable for all students, regardless of their backgrounds. Recognizing and addressing the diversity of cultures, perspectives, and student experiences in STEM is crucial. Teachers must actively work to create a STEM learning environment that is responsive to inclusiveness (Edelen & Bush, 2021) and promotes positive perceptions of STEM learning among students (Clements et al., 2021).

Lastly, effective pedagogy in STEM education necessitates continuous evaluation and reflection on teaching practices. Teachers should consistently assess student learning outcomes, adapt learning methods, and seek professional development opportunities to enhance their teaching skills in STEM. Reflection plays a crucial role in deepening knowledge about STEM issues, evaluating pedagogical practices, including inclusivity, and improving STEM learning planning (Archer et al., 2022; ElSayary, 2021; Sahin & Top, 2015). By implementing effective pedagogy, educators can better prepare students for success in the STEM field, contributing to the advancement of knowledge in STEM education and learning.

CONCLUSION AND RECOMMENDATION

The exploration of STEM education and learning has been a subject of study to gain a comprehensive understanding of its context, existing challenges, and effective teaching methods. Ongoing research in the field is contributing to the development of STEM education, positively impacting students' knowledge, problem-solving abilities, critical thinking, and mastery of concepts. Various challenges exist in STEM education, including pedagogical, curriculum, structural, student-related, assessment, and teacher support issues. Among these, the pedagogical challenge holds utmost significance as teachers play a crucial role in shaping STEM education within schools. Numerous aspects of effective pedagogy in STEM education have been identified, such as creating an innovative learning environment that fosters inquiry, experimentation, and critical thinking. Additionally, the use of diverse and relevant learning

resources and authentic learning methods is emphasized. Facilitating collaborative and inclusive learning environments, as well as encouraging reflection and continuous improvement in teaching practices, are also key components of successful STEM education and learning approaches.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Acknowledgement

The author expresses sincere appreciation to everyone who has contributed to this study. A special acknowledgment is directed towards the universities that have provided invaluable moral and material support during the entire research journey.

Declaration of Interest

The authors declare no conflict of interest.

REFERENCES

Aeschlimann, B., Herzog, W., & Makarova, E. (2016). How to foster students' motivation in mathematics and science classes and promote students' STEM career choice. A study in Swiss high schools. *International Journal of Educational Research*, *79*, 31–41. https://doi.org/10.1016/j.ijer.2016.06.004

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education*, *27*(1), 63–88. https://doi.org/10.1007/s10798-015-9341-0

Archer, L., Godec, S., Patel, U., Dawson, E., & Calabrese Barton, A. (2022). 'It really has made me think': Exploring how informal STEM learning practitioners developed critical reflective practice for social justice using the Equity Compass tool. *Pedagogy, Culture & Society*, *0*(0), 1–23. https://doi.org/10.1080/14681366.2022.2159504

Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM Education in Secondary Science Contexts. *Interdisciplinary Journal of Problem-Based Learning*, *6*(2). https://doi.org/10.7771/1541-5015.1349

Bagiati, A., & Evangelou, D. (2015). Engineering curriculum in the preschool classroom: The teacher's experience. *European Early Childhood Education Research Journal*, *23*(1), 112–128. https://doi.org/10.1080/1350293X.2014.991099

Bell, D. (2016). The reality of STEM education, design and technology teachers' perceptions: A phenomenographic study. *International Journal of Technology and Design Education*, *26*(1), 61–79. https://doi.org/10.1007/s10798-015-9300-9

Bennett, D., Knight, E., Dockery, A. M., & Bawa, S. (2020). Pedagogies for employability: Understanding the needs of STEM students through a new approach to employability development. *Higher Education Pedagogies*, *5*(1), 340–359. https://doi.org/10.1080/23752696.2020.1847162

Biazus, M. de O., & Mahtari, S. (2022). The Impact of Project-Based Learning (PjBL) Model on Secondary Students' Creative Thinking Skills. *International Journal of Essential Competencies in Education*, *1*(1), 38–48. https://doi.org/10.36312/ijece.v1i1.752

Bilad, M. R., Anwar, K., & Hayati, S. (2022). Nurturing Prospective STEM Teachers' Critical Thinking Skill through Virtual Simulation-Assisted Remote Inquiry in Fourier

Transform Courses. *International Journal of Essential Competencies in Education*, *1*(1), Article 1. https://doi.org/10.36312/ijece.v1i1.728

Bilad, M. R., Doyan, A., & Susilawati, S. (2022). Analyzing STEM Students' Critical Thinking Performance: Literacy Study on the Polymer Film Fabrication Process Irradiated with Gamma Rays. *International Journal of Essential Competencies in Education*, *1*(2), Article 2. https://doi.org/10.36312/ijece.v1i2.782

Börner, K., Scrivner, O., Gallant, M., Ma, S., Liu, X., Chewning, K., Wu, L., & Evans, J. A. (2018). Skill discrepancies between research, education, and jobs reveal the critical need to supply soft skills for the data economy. *Proceedings of the National Academy of Sciences*, *115*(50), 12630–12637. https://doi.org/10.1073/pnas.1804247115

Clark, R., & Andrews, J. (2010). Researching primary engineering education: UK perspectives, an exploratory study. *European Journal of Engineering Education*, *35*(5), 585–595. https://doi.org/10.1080/03043797.2010.497551

Clements, D. H., Vinh, M., Lim, C.-I., & Sarama, J. (2021). STEM for Inclusive Excellence and Equity. *Early Education and Development*, *32*(1), 148–171. https://doi.org/10.1080/10409289.2020.1755776

Coufal, P. (2022). Project-Based STEM Learning Using Educational Robotics as the Development of Student Problem-Solving Competence. *Mathematics*, *10*(23), Article 23. https://doi.org/10.3390/math10234618

Dalal, M., Carberry, A. R., & Maxwell, R. (2022). Broadening the Pool of Precollege Engineering Teachers: The Path Experienced by a Music Teacher. *IEEE Transactions on Education*, *65*(3), 344–355. https://doi.org/10.1109/TE.2022.3141984

Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2014). Driven by Beliefs: Understanding Challenges Physical Science Teachers Face When Integrating Engineering and Physics. *Journal of Pre-College Engineering Education Research (J-PEER)*, *4*(2). https://doi.org/10.7771/2157-9288.1098

Delen, I., & Sen, S. (2023). Effect of design-based learning on achievement in K-12 education: A meta analysis. *Journal of Research in Science Teaching*, *60*(2), 330–356. https://doi.org/10.1002/tea.21800

Diaz Eaton, C., Bonner, K., Cangialosi, K., Dewsbury, B., Diamond-Stanic, M., Douma, J., Smith, M., Taylor, R., Wojdak, J., & Wilfong, K. (2022). Sustainability and Justice: Challenges and Opportunities for an Open STEM Education. *CBE—Life Sciences Education*, *21*(3), es4. https://doi.org/10.1187/cbe.20-08-0180

Diekman, A. B., & Benson-Greenwald, T. M. (2018). Fixing STEM Workforce and Teacher Shortages: How Goal Congruity Can Inform Individuals and Institutions. *Policy Insights from the Behavioral and Brain Sciences*, *5*(1), 11–18. https://doi.org/10.1177/2372732217747889

Domenici, V. (2022). STEAM Project-Based Learning Activities at the Science Museum as an Effective Training for Future Chemistry Teachers. *Education Sciences*, *12*(1), Article 1. https://doi.org/10.3390/educsci12010030

Dong, Y., Wang, J., Yang, Y., & Kurup, P. M. (2020). Understanding intrinsic challenges to STEM instructional practices for Chinese teachers based on their beliefs and knowledge base. *International Journal of STEM Education*, *7*(1), 47. https://doi.org/10.1186/s40594-020-00245-0

Du, X., & Lyublinskaya, I. (2023). Study of computer attitudes in STEM problem-solving for students with disabilities. *Computer Applications in Engineering Education*, *31*(1), 117–130. https://doi.org/10.1002/cae.22574

Edelen, D., & Bush, S. B. (2021). Moving Toward Inclusiveness in STEM With Culturally Responsive Teaching. *Kappa Delta Pi Record*. https://www.tandfonline.com/doi/abs/10.1080/00228958.2021.1935178

Ekayanti, B. H., Prayogi, S., & Gummah, S. (2022). Efforts to Drill the Critical Thinking Skills on Momentum and Impulse Phenomena Using Discovery Learning Model. *International Journal of Essential Competencies in Education*, *1*(2), Article 2. https://doi.org/10.36312/ijece.v1i2.1250

EL-Deghaidy, H., Mansour, N., Alzaghibi, M., & Alhammad, K. (2017). Context of STEM Integration in Schools: Views from In-service Science Teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(6). https://doi.org/10.12973/eurasia.2017.01235a

ElSayary, A. (2021). Using a Reflective Practice Model to Teach STEM Education in a Blended Learning Environment. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(2). https://eric.ed.gov/?id=EJ1289486

Gasman, M., & Nguyen, T.-H. (2016). Engaging voices: Methods for studying STEM education at Historically Black Colleges and Universities (HBCUs). *Journal for Multicultural Education*, *10*(2), 194–205. https://doi.org/10.1108/JME-01-2016-0011

Goodpaster, K. P. S., Adedokun, O. A., & Weaver, G. C. (2012). Teachers' Perceptions of Rural STEM Teaching: Implications for Rural Teacher Retention. *Rural Educator*, *33*(3), 9–22.

Hernandez, D., Rana, S., Alemdar, M., Rao, A., & Usselman, M. (2016). Latino parents' educational values and STEM beliefs. *Journal for Multicultural Education*, *10*(3), 354–367. https://doi.org/10.1108/JME-12-2015-0042

Herro, D., & Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: Implications for teacher educators. *Professional Development in Education*, *43*(3), 416–438. https://doi.org/10.1080/19415257.2016.1205507

Hidayat, R., & Evendi, E. (2022). The Intervention of Mathematical Problem-Solving Model on the Systems of Linear Equation Material: Analysing its Impact on Increasing Students' Creative Thinking. *International Journal of Essential Competencies in Education*, *1*(2), Article 2. https://doi.org/10.36312/ijece.v1i2.1069

Ho, M.-T., La, V.-P., Nguyen, M.-H., Pham, T.-H., Vuong, T.-T., Vuong, H.-M., Pham, H.-H., Hoang, A.-D., & Vuong, Q.-H. (2020). An analytical view on STEM education and outcomes: Examples of the social gap and gender disparity in Vietnam. *Children and Youth Services Review*, *119*, 105650. https://doi.org/10.1016/j.childyouth.2020.105650

Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of "STEM education" in K-12 contexts. *International Journal of STEM Education*, *5*(1), 32. https://doi.org/10.1186/s40594-018-0127-2

Holstein, K. A., & Keene, K. A. (2013). The Complexities and Challenges Associated with the Implementation of a STEM Curriculum. *Teacher Education and Practice*, *26*(4), 616–636.

Hsu, Y.-C. (2021). An Action Research in Critical Thinking Concept Designed Curriculum Based on Collaborative Learning for Engineering Ethics Course. *Sustainability*, *13*(5), Article 5. https://doi.org/10.3390/su13052621

Kayan-Fadlelmula, F., Sellami, A., Abdelkader, N., & Umer, S. (2022). A systematic review of STEM education research in the GCC countries: Trends, gaps and barriers. *International Journal of STEM Education*, *9*(1), 2. https://doi.org/10.1186/s40594-021-00319-7

Kilty, T. J., & Burrows, A. C. (2022). Integrated STEM and Partnerships: What to Do for More Effective Teams in Informal Settings. *Education Sciences*, *12*(1), Article 1. https://doi.org/10.3390/educsci12010058

Knestis, K., Cheng, J., Fontaine, C. M., & Feng, R. (2022). Engaging Government-Industry-University Partnerships to Further Gender Equity in STEM Workforce Education Through Technology and Information System Learning Tools. *Journal of Information Systems Education*, *33*(1), 23.

Lange, C., Costley, J., & Fanguy, M. (2021). Collaborative group work and the different types of cognitive load. *Innovations in Education and Teaching International*, *58*(4), 377–386. https://doi.org/10.1080/14703297.2020.1788970

Lee, M.-H., Chai, C. S., & Hong, H.-Y. (2019). STEM Education in Asia Pacific: Challenges and Development. *The Asia-Pacific Education Researcher*, *28*(1), 1–4. https://doi.org/10.1007/s40299-018-0424-z

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting Middle School Teachers' Implementation of STEM Design Challenges. *School Science and Mathematics*, *116*(4), 177–188. https://doi.org/10.1111/ssm.12172

Leung, A. (2020). Boundary crossing pedagogy in STEM education. *International Journal of STEM Education*, *7*(1), 15. https://doi.org/10.1186/s40594-020-00212-9

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2019). Design and Design Thinking in STEM Education. *Journal for STEM Education Research*, *2*(2), 93–104. https://doi.org/10.1007/s41979-019-00020-z

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(1), 2. https://doi.org/10.1186/s40594-018-0151-2

Miller-Idriss, C., & Hanauer, E. (2011). Transnational higher education: Offshore campuses in the Middle East. *Comparative Education*, *47*(2), 181–207. https://doi.org/10.1080/03050068.2011.553935

Mulnix, A. B. (2016). STEM Faculty as Learners in Pedagogical Reform and the Role of Research Articles as Professional Development Opportunities. *CBE—Life Sciences Education*, *15*(4), es8. https://doi.org/10.1187/cbe.15-12-0251

Mutambara, D., & Bayaga, A. (2021). Determinants of mobile learning acceptance for STEM education in rural areas. *Computers & Education*, *160*, 104010. https://doi.org/10.1016/j.compedu.2020.104010

Nadelson, L. S., & Seifert, A. (2013). Perceptions, Engagement, and Practices of Teachers Seeking Professional Development in Place-Based Integrated STEM. *Teacher Education and Practice*, *26*(2), 242–266.

Oyewo, O. A., Ramaila, S., & Mavuru, L. (2022). Harnessing Project-Based Learning to Enhance STEM Students' Critical Thinking Skills Using Water Treatment Activity. *Education Sciences*, *12*(11), Article 11. https://doi.org/10.3390/educsci12110780

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

Park, M.-H., Dimitrov, D. M., Patterson, L. G., & Park, D.-Y. (2017). Early childhood teachers' beliefs about readiness for teaching science, technology, engineering, and mathematics. *Journal of Early Childhood Research*, *15*(3), 275–291. https://doi.org/10.1177/1476718X15614040

Peña, M., Olmedo-Torre, N., Mas De Les Valls, E., & Lusa, A. (2021). Introducing and Evaluating the Effective Inclusion of Gender Dimension in STEM Higher Education. *Sustainability*, *13*(9), 4994. https://doi.org/10.3390/su13094994

Prahani, B. K., Dawana, I. R., Jatmiko, B., & Amelia, T. (2023). Research Trend of Big Data in Education During the Last 10 Years. *International Journal of Emerging Technologies in Learning (IJET)*, *18*(10), 39–64. https://doi.org/10.3991/ijet.v18i10.38453

Ryoo, J., & Winkelmann, K. (Eds.). (2021). *Innovative Learning Environments in STEM Higher Education: Opportunities, Challenges, and Looking Forward*. Springer International Publishing. https://doi.org/10.1007/978-3-030-58948-6

Ryu, M., Mentzer, N., & Knobloch, N. (2019). Preservice teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation. *International Journal of Technology and Design Education*, *29*(3), 493–512. https://doi.org/10.1007/s10798-018-9440-9

Sahin, A., & Top, N. (2015). Teachers' Reflections on STEM Students on the Stage (SOS)TM Model. In A. Sahin (Ed.), *A Practice-based Model of STEM Teaching* (pp. 205–224). SensePublishers. https://doi.org/10.1007/978-94-6300-019-2_15

Schmidt, J. A., Beymer, P. N., Rosenberg, J. M., Naftzger, N. N., & Shumow, L. (2020). Experiences, activities, and personal characteristics as predictors of engagement in STEM-focused summer programs. *Journal of Research in Science Teaching*, *57*(8), 1281–1309. https://doi.org/10.1002/tea.21630

Scogin, S. C., Marks, M., Mader, C., & Phillips, K. (2023). Building motivationally supportive course-based research experiences for undergraduates: A self-determination theory perspective. *Higher Education Pedagogies*, *8*(1), 2165528. https://doi.org/10.1080/23752696.2023.2165528

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, *4*(1), 13. https://doi.org/10.1186/s40594-017-0068-1

Sidekerskienė, T., & Damaševičius, R. (2023). Out-of-the-Box Learning: Digital Escape Rooms as a Metaphor for Breaking Down Barriers in STEM Education. *Sustainability*, *15*(9), 7393. https://doi.org/10.3390/su15097393

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of Problem-Based Learning (PBL) in STEM Education: Using Expert Wisdom and Research to Frame Educational Practice. *Education Sciences*, *12*(10), Article 10. https://doi.org/10.3390/educsci12100728

Sochacka, N. W., Guyotte, Kelly. W., & Walther, J. (2016). Learning Together: A Collaborative Autoethnographic Exploration of STEAM (STEM + the Arts) Education. *Journal of Engineering Education*, *105*(1), 15–42. https://doi.org/10.1002/jee.20112

Tabarés, R., & Boni, A. (2023). Maker culture and its potential for STEM education. *International Journal of Technology and Design Education*, *33*(1), 241–260. https://doi.org/10.1007/s10798-021-09725-y

Van Haneghan, J. P., Pruet, S. A., Neal-Waltman, R., & Harlan, J. M. (2015). Teacher Beliefs about Motivating and Teaching Students to Carry out Engineering Design Challenges: Some Initial Data. *Journal of Pre-College Engineering Education Research (J-PEER)*, *5*(2). https://doi.org/10.7771/2157-9288.1097

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, *72*, 577–588. https://doi.org/10.1016/j.chb.2017.03.010

Varma, R., Falk, J. H., & Dierking, L. D. (2023). Challenges and Opportunities: Asian Women in Science, Technology, Engineering, and Mathematics. *American Behavioral Scientist*, *67*(9), 1063–1073. https://doi.org/10.1177/00027642221078509

Wahyudi, W., Verawati, N. N. S. P., Ayub, S., & Prayogi, S. (2019). The Effect of Scientific Creativity in Inquiry Learning to Promote Critical Thinking Ability of Prospective Teachers. *International Journal of Emerging Technologies in Learning (IJET)*, *14*(14), Article 14. https://doi.org/10.3991/ijet.v14i14.9532

Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM Integration: Teacher Perceptions and Practice. *Journal of Pre-College Engineering Education Research*, *1*(2). https://www.learntechlib.org/p/160807/

Wang, J., Guo, D., & Jou, M. (2015). A study on the effects of model-based inquiry pedagogy on students' inquiry skills in a virtual physics lab. *Computers in Human Behavior*, *49*, 658–669. https://doi.org/10.1016/j.chb.2015.01.043

Wirzal, M. D. H., Halim, N. S. A., Md Nordin, N. A. H., & Bustam, M. A. (2022). Metacognition in Science Learning: Bibliometric Analysis of Last Two Decades. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *6*(1), 43–60. https://doi.org/10.36312/esaintika.v6i1.665