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A Systematic Review of STEM Teaching in Higher Education (2014-2023)

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Abstract

This review examines the significant benefits and challenges of STEM (Science, Technology, Engineering, and Mathematics) education in higher education. Through a systematic review of literature from the past decade, the study summarizes transformative trends in STEM education, including enhancing student engagement, fostering innovative thinking, and developing problem-solving skills. Additionally, STEM education promotes interdisciplinary collaboration and the enhancement of social skills. However, practical implementation faces complex challenges, such as difficulties in applying digital technologies, resistance to pedagogical change, insufficient resources, and the integration of sustainability education. Achieving the full potential of STEM education requires collaborative efforts among educators, decision-makers, and institutions to create a more inclusive and adaptive educational environment, supporting students' success in rapidly evolving job markets.

Keywords: Stem, Teaching, Higher Education, Science, Technology, Engineering, Mathematics, Tertiary Education, Post-Secondary Education

Introduction

STEM education represents education in the four major fields of Science,Technology, Engineering, and Mathematics. Over the past decade, STEM education has undergone significant changes in response to emerging educational paradigms, advancements in pedagogical research, and the increasing demand for a skilled STEM workforce(Achat-Mendes et al., 2020).

Recognizing the growing demand for STEM-skilled professionals across various sectors, including education, healthcare, and government, higher education institutions worldwide have increasingly focused on adapting their curricula to prepare students for rapidly changing job markets. This adaptation goes beyond providing technical knowledge, encompassing essential soft skills such as communication, teamwork, and adaptability (Holik et al., 2023).

Moreover, STEM education plays a pivotal role in addressing complex, interdisciplinary challenges, such as climate change, public health crises, and sustainable development. By equipping students with the tools to think critically, analyze data, and solve problems, STEM education prepares them to contribute meaningfully to society and the economy. Research consistently shows that students engaged in STEM education demonstrate superior academic performance(Bickford et al., 2020), enhanced critical thinking, and better employment prospects(Rifandi & Rahmi, 2019).

In this context, the integration of technology, pedagogical innovations, and a deeper understanding of cognitive processes has fueled a shift from traditional teaching methods towards more interactive, student-centered approaches(Al Hamad et al., 2024). These new approaches prioritize active learning, problem-based learning, and the integration of technology to create more engaging and effective educational experiences.

As STEM disciplines continue to evolve, a systematic review of the teaching landscape becomes imperative. This review not only consolidates the existing knowledge but also identifies gaps and areas for future exploration. Understanding the trajectory of STEM education from 2014 to 2023 provides valuable insights for educators, researchers, and policymakers striving to enhance the quality and effectiveness of higher education in STEM disciplines. As improvements in STEM education will better prepare students for successful careers in a rapidly changing world.

This systematic review focuses on two core questions related to STEM teaching in higher education, providing a comprehensive summary and classification.
RQ1:What are the evident benefits of STEM education in higher education.
RQ2:What are the primary challenges faced in the practical implementation of STEM in higher education?

The first research question (RQ1) seeks to explore the evident benefits of STEM education in higher education. Understanding the tangible advantages that STEM education brings to learners and institutions is pivotal in fostering its continued integration into curricula.Simultaneously, the second research question (RQ2) focuses on identifying and comprehending the primary challenges faced in the practical implementation of STEM in higher education. Recognizing and addressing these challenges are essential steps toward optimizing the effectiveness of STEM education, ensuring its relevance and accessibility across diverse educational settings.

As we embark on this systematic review, we aim to provide a comprehensive analysis of the existing literature, shedding light on the multifaceted dimensions of STEM education in higher learning institutions.

Transformative Trends in STEM Education
In the past decade, STEM (Science, Technology, Engineering, and Mathematics) education has emerged as a focal point in higher education, undergoing significant transformations influenced by societal, economic, and technological developments. The knowledge landscape within STEM has become increasingly intricate, leading to a blurring of traditional disciplinary boundaries(Wei & Chen, 2020).

Recognizing that singular disciplines fall short in addressing complex real-world problems, there is a notable trend towards interdisciplinary integration, aiming to merge science, technology, engineering, and mathematics into a comprehensive academic framework. This integration not only better reflects the complexity of real-world issues but also cultivates students' holistic thinking and problem-solving abilities(Truesdell, 2014).

Traditional STEM education emphasized the imparting of theoretical knowledge, but a paradigm shift towards practice-oriented learning has become mainstream(Mohanta H. C., 2024). Students are no longer passive recipients of knowledge; instead, they apply learned concepts through participation in practical projects, experiments, and engineering practices(Felder & Brent, 2024). This hands-on, practice-oriented learning not only aligns better with professional demands but also enhances students' motivation and depth of understanding.

Educators increasingly favor the integration of advanced technologies, such as virtual laboratories, online simulations, and remote internships, to enrich teaching methods and provide more personalized learning experiences(Abouhashem et al., 2021; Skliarova et al., 2022; McGivney, 2023). This trend propels educational innovation, enabling students to better adapt to the demands of technological advancements. With the proliferation of digital technologies, STEM education is poised to leverage online education and remote learning platforms more extensively. This provides greater flexibility, enabling students to access high-quality STEM education globally.

Professions in STEM fields often require teamwork and interdisciplinary communication skills (Kilty & Burrows, 2022). Consequently, recent STEM education focuses on nurturing students' collaborative and communication skills. Project-based learning, group research, and practical engineering experiences have become common teaching methods, aiding students in developing efficient teamwork and communication abilities.

While traditional STEM education leaned towards theoretical knowledge transfer, modern STEM education prioritizes addressing real-world issues(Nguyen, 2023). By combining course content with challenges from the actual world, students gain a better understanding of practical knowledge application, enhancing their problem-solving skills. This problem-driven learning approach sparks student interest, making learning more meaningful.

These trends collectively shape a new landscape for STEM education, challenging traditional teaching approaches and prompting educators to focus more on students' actual needs and the future directions of their careers.

STEM Teaching in Higher Education

STEM teaching in higher education encompasses the delivery of educational content and methodologies within the domains of Science, Technology, Engineering, and Mathematics. It involves instructing and engaging students in courses and programs that foster critical thinking, problem-solving skills, and practical applications within these disciplines(English L. D., 2023; Siregar N. C. et al., 2024). In STEM higher education, instructors often employ a variety of teaching strategies, ranging from traditional lectures to active-learning approaches, hands-on laboratory work, and collaborative projects(Suhonen S. & Tiili J., 2024). The goal is not only to impart theoretical knowledge but also to cultivate a deep understanding of STEM concepts and their real-world applications. STEM education in higher institutions plays a crucial role in preparing students for careers in science, technology, engineering, and mathematics, contributing to innovation, research, and advancements in these fields(Idris R. et al., 2023). However, it also faces challenges related to the implementation of effective teaching practices, adapting to diverse learning styles, and ensuring that students acquire both theoretical knowledge and practical skills essential for their future endeavors.

Methods

The systematic review process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure the systematic and transparent nature of the evaluation. The study aimed to identify and retrieve articles related to STEM teaching in higher education, primarily utilizing the Scopus and Web of Science (WoS) databases for comprehensive literature searches. During the initial screening, a rapid review of titles and abstracts was conducted to exclude literature that did not meet the predefined criteria. Subsequently, a full-text review of the initially screened eligible literature was performed, ultimately identifying literature that met the standards for systematic review. Necessary data, including authorship, publication date, research design, and key findings, were extracted from the selected literature. The extracted data were then comprehensively analyzed to address the research questions. The entire evaluation process underwent careful scrutiny and deliberation, ensuring the scientific rigor of the methods employed and the credibility of the conclusions. By adhering closely to the PRISMA guidelines, the review ensured rigor and repeatability in the evaluation process.

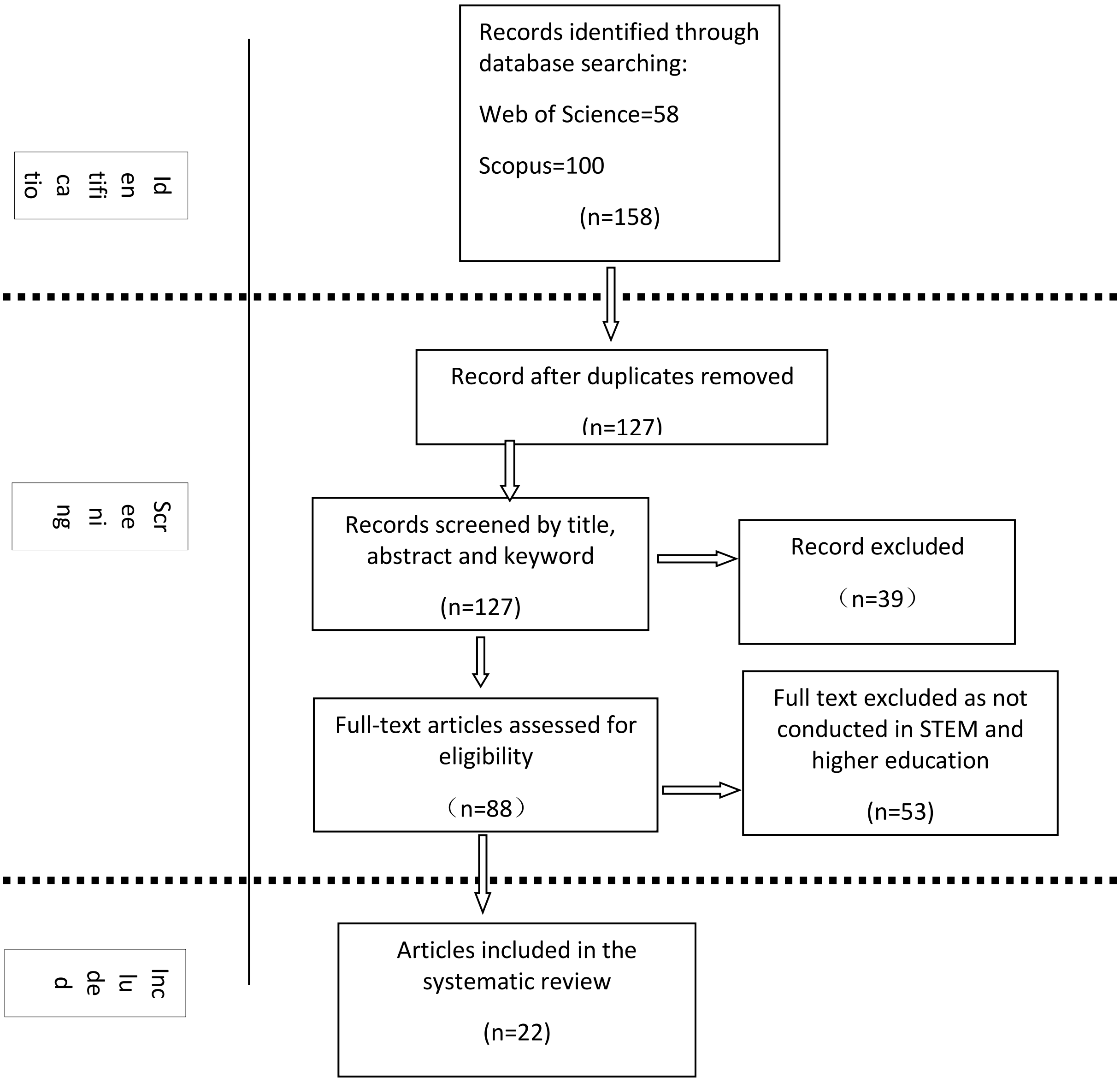

Figure 1. Flow diagram of the study (PRISMA systematic review)

The Review Protocol (PRISMA)

The systematic review paper on STEM education adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a widely acknowledged framework in the educational field(Rafiq K. R. M. et al., 2021). In the STEM context, PRISMA provides distinct advantages: firstly, it assists in formulating precise research questions, fostering systematic inquiries into STEM education practices. Secondly, it aids in identifying exclusion and inclusion criteria, ensuring transparency in study selection. Lastly, PRISMA facilitates a structured examination of extensive scientific literature databases, allowing for a comprehensive exploration of STEM education studies. This methodological approach proves invaluable for scrutinizing diverse STEM practices, contributing to a nuanced understanding of effective strategies in STEM teaching and learning.

Identification

The first stage involves identification, where key terms, synonyms, and variations related to the study's keywords "STEM," "teaching," and "higher education" are identified as search strings for databases. This process entails using Boolean operators, phrase searches, and truncation in databases, primarily Scopus and Web of Science. These databases are leading in the field of systematic reviews due to their comprehensive content and advanced retrieval capabilities. The purpose of this stage is to provide additional search options for the identified databases, ensuring a more extensive search for relevant articles to be included in the systematic review. This ensures that the review maintains high quality in terms of comprehensiveness and depth.

Table 1
The search string used for the systematic review process

Database	**Search String**
Web of Science(WoS)	TS=(("science, technology, engineering and mathematics" OR "STEM") AND ("higher education" OR "tertiary education" OR "post-secondary* education" OR "university education") AND ("teaching methods" OR "teaching strategies" OR "teaching styles" OR "teaching technique" OR "teaching innovation"))
Scopus	TITLE-ABS-KEY(("science, technology, engineering and mathematics" OR "STEM") AND ("higher education" OR "tertiary education" OR "post-secondary* education" OR "university education") AND ("teaching methods" OR "teaching strategies" OR "teaching styles" OR "teaching technique" OR "teaching innovation"))

Through these search strings, a comprehensive scope of literature addressing the benefits and challenges of STEM education in higher education is intended. This inclusive search approach aims to encompass a broad spectrum of studies, contributing to a thorough and representative review of the subject matter.

Screening
In the screening phase of this systematic review, specific inclusion criteria are applied to select articles for analysis. The selected articles fall within the publication timeframe of 2014 to 2023, ensuring the incorporation of the latest research in STEM teaching in higher education. The primary focus is on articles addressing STEM education, and exclusions are made for studies not conducted in English, lacking full-text availability (e.g., abstracts or conference posters), and unrelated to the research questions outlined in the introduction.The criteria further eliminate articles that do not furnish adequate information regarding their methodology or results.

Table 2
Inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Timeline	Between 2014 and 2023	<2014
Literature type	Articles from journals	Conference proceedings, review articles, book chapters, reports, retracted publication
Language	English	Non-English
Scope	Related to STEM and higher education	Not related to STEM and higher education

Included
Table 3
Summary of the selected studies

Study	Database	Aim	Samples	Findings
Ballen C. J. et al.(2019)	Scopus, WoS	To investigate factors influencing female participation in STEM classrooms during the transition from lecturing to active learning.	Over 5300 student–instructor interactions observed across multiple institutions in higher education STEM classrooms.	Increasing class size has the largest negative effect on female participation. However, employing diverse teaching strategies and incorporating small group interactions positively influence female participation, mitigating the challenges associated with large class sizes.
Chonsalasin D. & Khampirat B. (2022)	Scopus, WoS	Investigate structural factors influencing engineering skill self-efficacy (ENSE) among engineering students in Thai universities, considering digital skills, learning strategies, and achievement goal orientation.	1,316 engineering students in Thailand surveyed through a questionnaire.	Digital skills, learning strategies, and achievement goals positively influence engineering students' self-efficacy. Learning strategies, associated with achievement goals, also positively correlate with digital skills. These results emphasize the need for educational development to enhance students' engineering self-efficacy in the digital era.

Study	Database	Aim	Samples	Findings
Craig C. A. et al.(2022)	WoS	To address STEM and sustainability gaps, the study implemented an interdisciplinary STEM-based sustainability curriculum in business management and STEM courses.	107 students (n=214) from two in-person and two online treatment courses, along with two control courses.	Significant improvement in sustainability cognition dimensions (environmental, social, and economic) was observed, but affective outcomes did not show significant changes. Implications include the need to explicitly include affective learning in future curricular designs.
Davey T. Salazar Luces J. V. & Davenport R. (2021)	WoS, Scopus	To enhance equitable access to high-quality STEM higher education, a modified holistic teaching approach, centered on individual students and tailored to diverse sociocultural contexts, was implemented and assessed.	Undergraduate engineering students at Tohoku University over three years.	The individual-centered teaching approach consistently improved student attainment and confidence compared to general discipline-based education research methods. The study points to the critical need for continued exploration of innovative educational approaches to ensure equitable access to high-quality STEM education.
Derting T. L. et al.(2016)	Scopus, WoS	Evaluate the effectiveness of the Faculty Institutes for Reforming Science Teaching IV (FIRST) program in enhancing teaching practices of postdoctoral scholars in STEM disciplines.	The study included matched pairs of FIRST program alumni and non-FIRST faculty members from various institution types, teaching similar courses.	FIRST faculty demonstrated enhanced learner-centered teaching practices, utilizing active learning more than non-FIRST counterparts. External reviews confirmed the learner-centered nature of FIRST faculty's class sessions.

Study	Database	Aim	Samples	Findings
Elmi C.(2020)	Scopus, WoS	To assess the academic and behavioral outcomes of implementing social and emotional learning (SEL) practices in a mineralogy course at a four-year university.	Approximately 45 students in a mineralogy course at a U.S. higher education institution, with varying academic ranks, ages, and majors in engineering, physics, and Earth and environmental sciences.	Implementing social and emotional learning (SEL) practices in a mineralogy course positively impacted academic outcomes, increased student interest in STEM, and fostered stress resilience and positive engagement, highlighting the significance of SEL in enhancing higher education experiences, particularly in STEM disciplines.
Felder R.M.（2021）	Scopus, WoS	To explore the contrasting paradigms in STEM education—traditional and emerging—amid pressures for reform, addressing design, delivery, and assessment.	University instructors and administrators	STEM education is undergoing a shift from traditional deductive approaches to an emerging paradigm that prioritizes inductive methods, professional skills, and active student engagement, demonstrating superior learning outcomes.
Fendos J.(2020)	Scopus, WoS	To explore barriers to awareness of evidence-based teaching (EBT) in low-awareness, low-support contexts (LALSCs), specifically in South Korea, and suggest solutions.	Higher education STEM instructors in South Korea, including full-time lecturers without research obligations (L) and professors with both research and teaching obligations (P).	Differences between Ls and Ps suggest Ls are more receptive to EBT. Student-focused solutions, institutional supports, and showcasing local efficacy evidence can improve EBT awareness. Unique obstacles in low-awareness contexts highlight the need for context-specific strategies, and local emphasis enhances EBT awareness activities.
Gudelj A. et al.(2021)	WoS	To assess students'	14 mathematics teachers and	A need for modernizing teaching methods in

Study	Database	Aim	Samples	Findings
		preferences, satisfaction, and perceptions of learning mathematical subjects in maritime higher education institutions across Croatia, Latvia, Estonia, and Poland.	340 students from the participating institutions in the MareMathics project during the summer semester of the 2019/2020 academic year.	maritime institutions for mathematics was revealed, suggesting emphasis on real-life problem-solving, increased use of modern IT methods, and enhanced student engagement.
Haag K. et al.(2023)	Scopus WoS	To assess whether co-teaching serves as an effective mechanism for promoting evidence-based teaching strategies in STEM higher education.	Science, technology, engineering, and mathematics (STEM) instructors, education development professionals, leaders who oversee teaching, and researchers	Co-teaching has potential to shift ways of thinking and pedagogical practices among undergraduate STEM faculty
Khatri R.(2017)	Scopus, WoS	To investigate widely adopted evidence-based innovations in undergraduate STEM education and understand factors influencing their adoption.	43 instructional innovations in STEM education, identified through a questionnaire sent to experts in STEM instruction.	43 instructional innovations in undergraduate STEM education, with a focus on 21 branded innovations that incorporate modest pedagogical changes and substantial long-term funding for broad adoption.
Lobos K. et al.(2021)	Scopus, WoS	To analyze the relation among STEM students learning beliefs at the beginning of ERT (T1) with their Learning	2063 students (32.3% females) from a university in Chile participated	It is relevant for teachers and institutions to promote beliefs that can relate to positive behaviors in their students.

Study	Database	Aim	Samples	Findings
		Management systems (LMS) time-on-task and their final academic performance (T2) during the first semester of ERT.		
Mikhaylovsky M. N. et al.(2021)	Scopus	To develop a new model for STEM education within the higher professional education system in Russia.	STEM and STEAM education as an innovative technology.	An innovative STEM education model is presented, focusing on the importance of comprehensive pedagogical training, collaboration among diverse professionals, and the implementation of STEAM education for the in-depth training of engineers.
Mustafa N.(2016)	Scopus, WoS	To examine instructional strategies dominating integrated STEM education and their impact on student development.	Review literature from various sources, including ERIC, online databases, and journals, covering integrated STEM education in primary, secondary, and tertiary settings.	Project-based learning emerged as the dominant and effective strategy in integrated STEM education, enhancing student interest, motivation, achievement, and fostering positive attitudes.
Sabah S. & Du X.(2018)	WoS	Investigate university STEM instructors' understanding, perceptions, and practices of student-centered learning (SCL) in Qatar.	STEM faculty in Qatar, mainly from science, technology, engineering, and mathematics fields.	STEM instructors in Qatar have inclusive definitions of student-centered learning (SCL), including lectures and problem-based teamwork, but there's a gap between perception and practice. Limited student–student interactions and rare formative assessments

Study	Database	Aim	Samples	Findings
				are attributed to external factors such as cultural influences and institutional constraints.
Sáiz-Manzanares M. C. et al.(2021)	Scopus, WoS	Investigate the impact of teacher expertise, gender, and type of qualification (STEM vs. Non-STEM) on the utilization of Moodle learning objects (resources and activities) in Higher Education.	13 teachers (6 e-Learning experts, 7 non-experts), 626 students (334 women, 292 men) from STEM and Non-STEM courses.	Significant differences in the utilization of Moodle learning objects were found based on teacher expertise, gender, and qualification type (STEM vs. Non-STEM) in Higher Education, indicating a need for enhanced technological training for inclusive and standardized online teaching.
Selco J. I. & Habbak M. (2021)	WoS	Investigate the effectiveness of emergency virtual instruction during the COVID-19 pandemic.	Surveyed 584 STEM students at California State Polytechnic University Pomona (Cal Poly Pomona).	62% of STEM students found virtual classes beneficial for flexibility and productivity, yet faced challenges in adapting and feeling disconnected; recommendations include clear instructions, flexibility, and fostering community.
Skliarova I. et al.(2023)	Scopus	To identifying online teaching strategies appropriate for blended and face-to-face higher STEM (Science, Technology, Engineering, Mathematics) education.	The STEM faculty of the University of Aveiro	Faculty in STEM education prefer on-campus teaching due to challenges in student motivation in distance education. Proposed strategies include enhancing technical infrastructure and providing extensive training support for more interactive online classes.

Study	Database	Aim	Samples	Findings
Smith M. K.(2014)	WoS	Examine STEM teaching practices at the University of Maine.	Observed 51 STEM courses across 13 departments, involving faculty teaching introductory and upper-division levels.	Identified a continuum of instructional behaviors among faculty, not strictly traditional lecturers or highly interactive instructors. Student behavior varies with lecture levels. Faculty, generally self-aware, exhibit a range of teaching practices. Implications for professional development include recognizing the continuum and leveraging faculty experiences.
Tekane R. & Potgieter M.(2021)	Scopus, WoS	This study addresses the lack of published research on successful teaching and learning strategies for blind and low-vision (BLV) students in STEM fields, focusing on science disciplines in South Africa.	The study reports on the successful teaching and learning strategies implemented for John, a blind student pursuing a biological sciences degree at a research-intensive university in South Africa.	Successful completion of John's bachelor's degree was attributed to factors such as dedicated tutors, a well-resourced Disability Unit (DU), accommodating lecturers, and John's commitment. The study highlights the importance of a collaborative effort and the need for disability awareness in STEM education for improved access and success of BLV students.
Walter E. M. et al.(2021)	WoS	To develop and validate the Survey of Climate for Instructional Improvement (SCII) to measure organizational climate in postsecondary settings, focusing	917 postsecondary instructors, including graduate student instructors, full-time, and part-time faculty from six U.S.	The Survey of Climate for Instructional Improvement (SCII), a reliable instrument, was developed and validated, revealing organizational climate differences between STEM and non-STEM disciplines and

Study	Database	Aim	Samples	Findings
		on leadership, collegiality, resources, respect for teaching, and organizational support.		identifying unique support needs for cis-gender women and graduate student instructors among 917 postsecondary instructors.
Wheeler L. B.et al.(2019)	Scopus, WoS	To explore graduate students' conceptions of and intentions to teach NOS in the context of a Teaching Methods in Higher Education course.	Thirteen graduate students from astronomy, biology, and civil engineering departments participating in a 1-credit Teaching Methods in Higher Education course.	The Teaching in Higher Education course significantly improved STEM graduate students' understanding of the nature of science (NOS), leading to enhanced NOS conceptions and increased intentions to use explicit instructional approaches when teaching NOS.

Data Synthesis
In the data synthesis phase, a narrative approach will be employed to comprehensively analyze the selected articles focusing on STEM teaching in higher education. The systematic collection and organization of relevant articles on STEM education have been meticulously managed using citation management software, EndNote.

Upon the completion of the collection process, a thematic analysis was conducted to address the following research questions:
RQ1:What are the evident benefits of STEM education in higher education?
RQ2:What are the primary challenges faced in the practical implementation of STEM in higher education?

The review employed an interpretive analysis of the selected articles, aiming to synthesize themes relevant to the specified research questions. For the first research question, the identified themes were distilled to capture the benefits of STEM education in higher education. The second research question involved summarizing themes related to the primary challenges encountered in the practical implementation of STEM in higher education.

Results
3.1 RQ1:What are the evident benefits of STEM education in higher education?
In this systematic review, STEM employs various benefits, broadly classified into (1) Improved student engagement and sustainability learning, (2) Advantages of the Application of

Instructional Technology, (3)Development of Critical Thinking and Problem-Solving Skills,(4)Interdisciplinary Collaboration and skills, (5)Social skills, (6)Encouraging innovation, (7)Foster an understanding of the Nature of Science.These classifications showcase the benefits utilized by STEM teaching in higher education.

Table 4
Benefits of STEM Education in Higher Learning

STEM benefits	**Study**
Improved student engagement and sustainability learning	Skliarova I. et al.(2023) Craig C. A. et al.(2022) Ballen C. J. et al. (2019)
Advantages of the Application of Instructional Technology	Felder R. M. (2021) Gudelj A. et al.(2021)
Development of Critical Thinking and Problem-Solving Skills	Mikhaylovsky et al. (2021) Felder R. M. (2021) Derting T. L. et al.(2016)
Fostering interdisciplinary Collaboration and skills	Haag, K. et al.(2023)
Social skills	Davey T. et al. (2021)
Encouraging innovation	Mikhaylovsky et al. (2021) Khatri et al. (2017) Selco J. I. & Habbak M. (2021) Sabah S. & Du X. (2018)
Foster an understanding of the Nature of Science	Wheeler L. B. et al. (2019)

Improved Student Engagement and Sustainability Learning
Skliarova et al (2023), conducted a study on the enhanced student engagement and learning outcomes associated with STEM education in higher education. The findings revealed a prevalent preference for on-campus teaching among both faculty and students over distance learning. The study identified a significant challenge in maintaining student engagement and motivation. To address this challenge, the researchers recommended the adoption of various teaching strategies, including case studies, debates, discussions, experiential learning, brainstorming sessions, and games. These strategies were proposed as effective means to create engaging classes and contribute to the perceived benefits of STEM education in higher education.

According to Craig et al (2022), the evident benefits of STEM education in higher education include improvements in sustainability knowledge and cognitive outcomes. The interdisciplinary nature of STEM-based sustainability curricula, when implemented effectively, leads to enhanced student understanding and application of economic, environmental, and social components of sustainability. The study reports significant improvement in sustainability knowledge for students who received STEM-based sustainability curricular interventions.

STEM education in higher education, particularly when conducted in smaller class sizes with diverse teaching methods, shows a positive impact. According to Ballen et al (2019), women were more likely to participate after engaging in small group discussions, which demonstrates the advantages of interactive and collaborative learning environments.

Advantages of the Application of Instructional Technology

STEM education has a positive impact on students' future careers, with project-based learning being highlighted as a prominent method in STEM research. This strategy is considered a positive avenue for meaningful learning, aiding in the development of students' confidence in choosing STEM careers in the future (Mustafa et al., 2016).

Gudelj et al (2021), found that most students are satisfied with the learning resources recommended by their teachers. These resources include teacher-created lecture notes, teaching materials published on the internet, and textbooks from other universities. Digital and online resources are easier to access and use, allowing students to continue learning outside the classroom.

The research conducted by Felder (2021), indicates that, on average, online and face-to-face courses yield comparable learning outcomes. Furthermore, hybrid courses, which integrate the most beneficial aspects of both online and face-to-face formats, have been demonstrated to be more effective than either face-to-face or online courses independently.

Development of Critical Thinking and Problem-Solving Skills

Mikhaylovsky et al (2021), propose a STEAM-education model for higher professional education.This model emphasizes open educational integration, discipline-specific knowledge support, and a strategic approach to integrated STEM learning.The organizational approach of this method in practical work promotes the development of critical thinking and analytical skills, enabling individuals to identify various alternative methods for problem-solving.

In comparing the two paradigms outlined by Felder (2021), the traditional paradigm places significant emphasis on acquiring facts, formulas, and honing analytical and computational problem-solving skills. In contrast, the emerging paradigm advocates a more balanced approach, placing equal importance on traditional content and the cultivation of critical thinking, creative thinking, multidisciplinary thinking, metacognition, communication, and teamwork skills.

Derting and Ebert-May's (2016), study indicates that professional development programs in STEM education, such as the FIRST project, have a positive impact on enhancing teachers' instructional practices and educational philosophies. The research reveals that teachers participating in the FIRST project made progress in adopting student-centered teaching approaches within STEM education. This approach is effective in nurturing students' critical thinking skills and problem-solving abilities.

Fostering Interdisciplinary Collaboration and Skills

Haag et al (2023), investigated co-teaching and found that despite considerable variation in the mindset and instructional practices of collaborating teachers, co-teaching consistently led to shifts in thinking and instructional approaches. Co-teaching has the potential to foster interdisciplinary collaboration and contribute to pedagogical change within STEM education in higher education.

Social Skills

Davey et al (2021), demonstrated that the DBER (Discipline-Based Education Research)-informed approach to STEM education has yielded positive outcomes, eliminating some artificial factors in education. The study provides evidence for the potential efficacy of an individual-centered approach in enhancing academic achievements and fostering additional social skills necessary for the modern educational and workplace environments.

Encouraging Innovation

In the in-depth interviews conducted by Mikhaylovsky et al (2021), all experts unanimously agreed that the STEM approach is presently acknowledged as a zone for experimentation, active exploration, and innovation within the educational domain (Segura, 2017). It has the potential to foster the development of a creative form of thinking in students.

Khatri et al (2017), discussed the characteristics of well-disseminated teaching strategies and materials in undergraduate STEM education, referred to as "Well-Propagated Instructional Strategies or Materials" (WePISMs). The study conducted an extensive survey across various STEM disciplines, identifying and categorizing 43 WePISMs, and providing a detailed list and description of these successfully propagated innovations. The research highlighted both the commonalities and differences among different STEM disciplines, emphasizing key features of successful educational innovations.

Selco & Habbak (2021), mentions one advantage of STEM education is enhancing student engagement and understanding through innovative assessment methods, such as performance tasks and creative questions.

Key Advantages of STEM Education in Higher Education, including active learning strategies such as Student-Centered Learning (SCL), have been proven to enhance student performance in the fields of Science, Technology, Engineering, and Mathematics (STEM). Sabah S. & Du X. (2018) indicate that female and younger faculty members are more inclined to adopt innovative teaching methods, highlighting the creative and innovative potential within STEM education.

Foster an Understanding of the Nature of Science

In the study conducted by Wheeler et al. (2019), findings indicate the potential effectiveness of STEM education in higher education. The results suggest that STEM graduate students, despite having limited formal teaching experience, can formulate innovative approaches to teaching Nature of Science (NOS). Furthermore, even graduate students with restricted teaching backgrounds have the capacity to deliver effective NOS instruction to undergraduate students.

RQ2:What are the primary challenges faced in the practical implementation of STEM in higher education?

According to the literature, challenges encountered in the practical integration of STEM in higher education can be succinctly summarized or synthesized into distinct groups, as outlined in Table 5.

Table 5
Categories of challenges faced in the practical implementation of STEM in higher education

Challenges	RelatedStudies
Digital technologies and active learning strategies	Lobos K. et al.(2021) Mikhaylovsky et al.(2021) Mustafa N. et al.(2016) Selco J. I. & Habbak M.(2021) Gudelj A. et al, (2021)
Pedagogical change	Haag K. et al.(2023) Felder R. M. (2021) Fendos J. (2020) Sabah S.& Du X. (2018)
Inadequate professional development	Skliarova I. et al.(2023) Mikhaylovsky et al. (2021)
Differences in the target audience for teaching	Wheeler L. B.et al.(2019), Davey T. et al.(2021) Sáiz-Manzanares et al.(2021)
Large class sizes	Ballen et al.(2019) Derting T. L. et al.(2016)
Sustainability education	Craig C. A. et al.(2022)
Insufficient resources and funding	Skliarova I. et al.(2023) Khatri R. et al.(2017)
Applicability and equitable education.	Davey T.et al.(2021) Tekane R. & Potgieter M. (2021)

Digital Technologies and Active Learning Strategies
The global trend of the digital economy underscores the necessity of integrating digital technologies into STEM education. In the implementation of STEM education, the utilization of digital technologies and e-learning systems holds significant importance(Mikhaylovsky et al., 2021; Gudelj et al., 2021). These elements are integral to the organization of education and training for students in general education schools, particularly in the field of natural sciences, as part of the ongoing adaptation to technological advancements.

In Lobos et al. study (2021), challenges in emergency remote teaching (ERT) for STEM education emerge, particularly due to the hands-on nature of STEM courses. Students express predominantly negative beliefs about learning opportunities, citing limitations in participating in hands-on activities. The challenges in STEM education during ERT include the crucial need for effective online instruction, active learning strategies, and tailored assessment designs. In virtual laboratory courses, there is a challenge in providing hands-on learning experiences for students. However, employing virtual demonstrations is an effective approach to address this challenge (Selco & Habbak, 2021).

The support for implementing integrated STEM education requires conducting more research to identify ideal strategies that enable students to have a better experience in STEM learning. Additionally, there is a need to investigate various strategies for planning and implementing activities that attract students' interest in the STEM field (Mustafa, 2016).

Pedagogical Change

Haag et al (2023), provide a definition of co-teaching in the context of STEM higher education and offer a comprehensive summary of the known aspects related to the pedagogical changes facilitated by co-teaching and the potential mechanisms driving these changes. In terms of pedagogical transformation, key challenges include deficiencies in collaborative teaching design and evaluation systems, particularly in the absence of adequate support for evidence-based teaching assessments. The formidable challenges posed by research design complexities and sample size limitations underscore the intricate nature and constraints within STEM education practices. These issues encapsulate the multi-faceted challenges faced by STEM education in practical application.

Despite pressures for reform and evidence supporting new teaching methods, many faculty members and administrators resist change.There is a debate between the traditional paradigm, dominant for decades, and the emerging paradigm, which is gaining acceptance but is not yet predominant in most universities and colleges.

Fendos (2020), identifies several impediments to the adoption of evidence-based teaching practices within STEM disciplines. Among these challenges are a deficiency in awareness and support for evidence-based teaching (EBT), resistance to change at institutional and cultural levels, restricted training opportunities for faculty, and complexities associated with transferring EBT practices across different institutions or countries. Institutionalized faculty development and support are crucial for the further implementation of innovative teaching strategies(Sabah & Du, 2018). When institutional structures are set up to function well with traditional teaching, they can become barriers that limit instructional innovation.

Inadequate Professional Development

Skliarova et al (2023), identified a significant obstacle: the difficulty of providing engaging and motivating classes for students. The authors suggested various teaching strategies, such as case studies, debates, discussions, experiential learning, brainstorming sessions, and games, as crucial for overcoming this challenge. Moreover, the proposals for enhancing distance education primarily revolved around developing a robust technical infrastructure, providing extensive training support from the university, and restructuring classes. The suggested improvements included shorter class durations, smaller student groups, and increased interactivity to address the complexities associated with STEM education implementation.

As emphasized by Grebenyuk and Bulan, there are such problems as the lack of professional training of teachers to use STEM education, the underdevelopment of curricula, teaching aids, criteria for assessing student achievement(Mikhaylovsky et al., 2021; Grebenyuk & Bulan, 2020). These challenges pose substantial obstacles to the effective implementation and success of STEM methodologies in educational settings.

Differences in the Target Audience for Teaching

In the study by Wheeler et al (2019), challenges in implementing STEM education are acknowledged. These challenges include constraints such as limited time available for Nature of Science (NOS) instruction and the possibility of variations in the effectiveness of NOS interventions across different instructor populations.

Sáiz-Manzanares et al (2021), found that gender differences linked to enrollment in STEM (Science, Technology, Engineering, and Mathematics) and non-STEM courses may influence the utilization of learning objects by students. The study identified variations between teachers and students concerning the use of Moodle learning objects, including resources and activities. Additionally, it highlighted gender and degree-related differences in the utilization of certain learning objects (Sáiz-Manzanares, 2021).

Large Class Sizes

The large class size has adverse effects on STEM education (Ballen et al., 2019), especially in introductory science courses. There is a call for a reassessment of the expansion of large classes and the necessity for inclusivity and equitable participation, particularly for female students. In Derting study (2016), participants in the FIRST project encountered challenges aligning assessments with instructional practices. Additionally, teachers faced difficulties in implementing student-centered teaching, especially in courses with large enrollments that required extensive time for grading.

Sustainability Education

Craig (2022), notes a notable challenge: the historical disparity in the receptiveness of STEM disciplines compared to non-STEM disciplines, such as business and management, towards sustainability curricula. STEM disciplines, particularly engineering and technology, have traditionally been more open to sustainability education. However, non-STEM disciplines, including business and management, may face barriers due to academic silos and differences in student characteristics. Overcoming these barriers requires collaborative efforts and innovative approaches to interdisciplinary integration. The study also highlights the need for effective instructional design and curriculum development to address these challenges.

Insufficient Resources and Funding

The finding from Khatri et al. article (2017), is that successful propagation of educational innovations requires long-time horizons (8-10 years minimum) and significant funding. This poses challenges as typical grant durations are shorter, suggesting the need for extension funding mechanisms (Khatri et al., 2017).

Applicability and Equitable Education

In STEM education, challenges related to applicability and equitable education involve unequal distribution of educational resources, variations in teaching methods, and the diversity among students. Addressing these challenges requires comprehensive teaching approaches and policies to foster an inclusive and fair learning environment. Ensuring that every student has equal opportunities to access high-quality education, regardless of their background or specific needs, is crucial(Davey et al., 2021). Challenges in implementing STEM education in higher education may encompass issues of research applicability, difficulties in data collection, and the potential impact of unforeseen events on the outcomes.

Tekane & Potgieter (2021), highlight various challenges faced by visually impaired students in STEM education, such as visual nature, mathematics and statistics, access to educational materials, and reliance on educational institutions. Special measures are implemented to enhance their adaptability and success. This underscores the prevailing inequality within the education system and emphasizes the need for greater efforts to enhance the participation and success of disabled students in the STEM field.

Discussion
The identified benefits of STEM education underscore its transformative potential in higher education. The themes extracted from the literature depict a spectrum of positive outcomes, from enhanced student engagement to the cultivation of critical thinking and problem-solving skills. The literature consistently highlights the efficacy of diverse teaching strategies, such as case studies(Gudelj et al., 2021), debates(Skliarova et al., 2023), and experiential learning(Mustafa et al., 2016), in fostering a dynamic and engaging STEM learning environment.

The integration of instructional technology and project-based learning emerges as a key catalyst for bridging the gap between theory and practice in STEM(Mustafa N. et al., 2016). The positive impact of active learning strategies, particularly in smaller class sizes, reinforces the significance of fostering interactive and collaborative learning environments(Ballen et al., 2019). Moreover, the recognition of STEM as a catalyst for innovation and experimentation signifies its potential to shape creative thinking in students.

On the flip side, the challenges in the practical implementation of STEM in higher education reveal the intricacies associated with this pedagogical approach. For instance, the demand for digital technologies often clashes with the hands-on nature of STEM courses(Selco & Habbak 2021). The challenges highlighted in emergency remote teaching (ERT) underscore the need for adaptive online instruction and tailored assessment designs to address the unique requirements of STEM education(Lobos et al., 2021).

Pedagogical change, as a fundamental aspect of STEM, encounters resistance at institutional and cultural levels. The tension between traditional and emerging paradigms within STEM disciplines reflects the ongoing struggle to embrace evidence-based teaching practices(Felder, 2021). Faculty development surfaces as a linchpin for overcoming this resistance, necessitating institutionalized support and comprehensive training programs.

Insufficient resources, funding limitations(Khatri et al., 2017), and the historical disparities in the acceptance of sustainability curricula within STEM disciplines pose formidable challenges. The identified barriers necessitate innovative approaches to interdisciplinary integration and effective instructional design to ensure the seamless incorporation of sustainability education into STEM programs.

The synthesis of a substantial body of literature illuminates the dynamic landscape of STEM education in higher education. The identified benefits showcase its potential to revolutionize learning outcomes and foster innovation. However, the challenges unveiled underscore the need for concerted efforts in addressing pedagogical, technological, and institutional barriers. As we navigate these challenges, recognizing the transformative potential of STEM education becomes paramount, urging stakeholders to collaborate in creating an inclusive, innovative, and adaptive educational environment that harnesses the full spectrum of benefits STEM has to offer.

Conclusions

Through an examination of STEM education in higher education, this review highlights significant benefits and challenges. STEM education has demonstrated substantial achievements in enhancing student engagement, fostering innovative thinking, and developing problem-solving skills. However, practical implementation faces complex challenges, including issues related to digital technology application, pedagogical change, and resource constraints.Despite being a transformative force in education, STEM encounters various obstacles such as conflicts in digital integration, resistance to pedagogical shifts, and limited resources. Promoting the implementation of STEM education requires collaborative efforts among educators, decision-makers, and institutions to create a more inclusive and adaptive educational environment. Only through such collective action can we fully unlock the potential of STEM education and cultivate future leaders in science, technology, engineering, and mathematics.

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