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The Evolution of STEM Education Research and Its Impact on Vietnam's Higher Education

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ABSTRACT

The 4.0 Industrial Revolution has propelled STEM education (Science, Technology, Engineering, Mathematics) into a global trend, emphasizing practical application and skills development. For Vietnamese universities, integrating STEM is critical to equipping graduates with 21st-century workforce competencies. STEM education fosters the creation of innovations such as smartphones, self-driving cars, and smart applications, necessitating well-trained scientists and engineers. To align with global trends, Vietnamese higher education prioritizes enhancing learners' capacities and creative thinking by focusing on teaching methodologies rather than solely content. Innovating teaching approaches and university training models is essential during this integration period.

This study explores the significance of STEM education in university-level Engineering programs, highlighting its advantages and its role as an effective educational solution. Using Harzing's Publish or Perish software to analyze Google Scholar data (2010–2024) with the keyword "University-level STEM education," the research evaluates the growth and impact of STEM education in Vietnam. It also examines challenges faced by educators and institutions in implementing STEM, proposing strategies to overcome these obstacles and improve teaching and learning outcomes in a modern educational context.

Keywords: STEM education, education, STEM teaching, university, electrical engineering.

INTRODUCTION

In the context of globalization and the Industry 4.0 revolution, undergraduate science, technology, engineering, and mathematics (STEM) education plays a pivotal role in training high-quality human resources to meet the increasing demands of the labor market (Andrews et al., 2022; Jamali et al., 2022). Undergraduate STEM education not only equips students with specialized knowledge but also develops essential skills such as critical thinking, problem-solving, and teamwork (Barlow & Brown, 2020; Reynders et al., 2020). Numerous studies have indicated that the adoption of active and innovative pedagogical approaches in STEM education can significantly enhance student engagement and learning outcomes (Apkarian et al., 2021; Henderson et al., 2011). In Vietnam, recognizing the importance of STEM education in the context of international integration, universities are striving to innovate their curricula and teaching methodologies towards STEM approaches (Bhatti, 2024). However, the effective implementation of undergraduate STEM education in Vietnam still faces several challenges. This paper aims to investigate the development of undergraduate STEM education globally and specifically analyze its impact on the higher education system in Vietnam, from curriculum design and the application of new teaching methods to the assessment of student learning outcomes.

OBJECTIVES

The primary objective of this paper is to analyze the development of STEM (Science, Technology, Engineering, and Mathematics) education research globally and in Vietnam, while evaluating its impacts on higher education in the Vietnamese context. Specifically, the paper aims to: (1) provide an overview of the evolution of STEM education, from foundational concepts to practical implementation models in higher education; (2) clarify the role of STEM research in shaping educational policies, curriculum design, and teaching methodologies at universities; (3) analyze both the positive impacts and the challenges that Vietnamese higher education institutions face in integrating STEM into academic programs; and (4) propose recommendations to enhance the effectiveness of STEM application in higher education, contributing to improved training quality and meeting the workforce demands of the Fourth Industrial Revolution. By addressing these objectives, the paper seeks not only to offer a systematic understanding of STEM education research but also to serve as a guide for policymakers, educators, and researchers in formulating strategic plans for the development of higher education in alignment with global trends and international integration.

METHODS

This study employs a qualitative research approach combined with document analysis to explore the development of STEM education and assess its impact on higher education in Vietnam. The research data were collected, analyzed, and visualized based on scientific articles, academic journals, and studies related to STEM education at the university level. The author searched for relevant publications using three major academic databases: Scopus, ERIC, and Google Scholar, ensuring both reliability and comprehensiveness of the data sources.

The search process involved the use of specific English keywords, including: “STEM-oriented university teaching”, “STEM education university teaching methods”, “STEM education for college students”, and “Teaching STEM to College Students”. The time frame was limited to publications from 2010 to 2024, reflecting the period of significant global and national development in STEM education. As a result, 48 English-language articles were identified that directly relate to STEM teaching at the university level.

After manual screening to remove duplicates and irrelevant content, the data were processed using Microsoft Excel for keyword tagging by author, descriptive statistical analysis, and chart generation. In addition, the VOSviewer tool was employed to conduct quantitative analysis and extract key research topics through keyword co-occurrence networks, thereby highlighting prevailing trends and major scholarly interests in contemporary STEM education. This methodological approach ensures a systematic, objective foundation aligned with the research aims of the paper.

RESULTS

ACCESSIBILITY OF STEM TO HIGHER EDUCATION IN VIETNAM

Challenges and opportunities of STEM approach to university teaching

Educational Resources: Undergraduate STEM education in Vietnam faces significant challenges regarding educational resources. The shortage of modern laboratories and advanced teaching technologies severely limits students' access to practical experience and up-to-date knowledge, contributing to the low enrollment rates in STEM fields. However, a promising window of opportunity is opening. The increased education budget, coupled with international collaboration projects and the involvement of technology corporations like Intel, is facilitating infrastructure upgrades. Cross-border partnerships and attracting private funding hold immense potential in providing cutting-edge equipment, enabling Vietnamese students to access leading technologies, thereby enhancing the quality of STEM training to meet the growing demands of the modern economy.

Curriculum: Another core challenge lies in the structure and content of STEM curricula at Vietnamese universities. Currently, many programs still lack the necessary interdisciplinary integration, tend to be heavily theoretical without adequately emphasizing the systematization of knowledge and skills within the formal curriculum. This directly limits students' ability to apply knowledge in real-world scenarios and develop essential practical skills. Nevertheless, initiatives such as learning design workshops are creating valuable opportunities to build more effective interdisciplinary STEM programs. Close collaboration with international universities and businesses can bring valuable updates, enhance practicality, and ensure alignment with the needs of the rapidly changing labor market.

Faculty Capacity: The capacity of the teaching staff plays a pivotal role in the effective implementation of STEM education, and this is also an area facing numerous challenges. Many faculty members may not be adequately equipped with the integrated and interdisciplinary teaching methods characteristic of STEM, while current professional development programs have limited scope and reach. However, workshops focusing on new technologies like artificial intelligence (AI) and learning design are opening up important opportunities to enhance

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faculty skills. Collaboration with reputable domestic universities and international organizations can provide continuous and specialized training programs, helping faculty confidently apply advanced STEM pedagogical methods effectively in the classroom environment.

Equitable Access: The issue of equitable access in STEM education in Vietnam remains a significant concern. The limited participation of female students and students from rural areas, often due to social biases and difficult economic conditions, poses a major barrier to the comprehensive development of the STEM workforce. However, programs such as STEM workshops for people with disabilities and the implementation of scholarship policies are creating opportunities to improve accessibility for these student groups. Additionally, awareness campaigns on the importance of diversity in STEM and financial support programs can play a crucial role in encouraging broader participation from various genders and regions.

Industry Collaboration: Collaboration between universities and businesses in the STEM fields in Vietnam remains insufficiently strong, leading to a significant gap between training content and the actual needs of the labor market. This often requires graduates to undergo additional training to meet job requirements. However, initiatives such as scientific research competitions and the establishment of strategic partnerships with businesses are opening up opportunities to provide valuable internship programs and flexibly update curricula. Strengthening systematic and effective collaboration between universities and businesses has immense potential in enhancing the practicality of STEM education, better preparing students for their careers in science, technology, engineering, and mathematics.

Some solutions to overcome the challenges of applying STEM to university teaching in Vietnam

Applying STEM to Vietnamese higher education is a process that requires investment and efforts from many sides. Below are some specific solutions to overcome the current challenges:

Enhancing Faculty Capacity: One of the major challenges in applying STEM in higher education in Vietnam is the lack of skills and experience among faculty in integrating interdisciplinary subjects. To address this, universities should organize intensive training programs on STEM teaching methods, focusing on designing integrated lessons that combine science, technology, engineering, and mathematics. Additionally, encouraging faculty to participate in international workshops or collaborate with foreign universities will help them stay updated with new trends and improve teaching quality.

Investing in Infrastructure and Technology: Limitations in infrastructure, modern laboratories, and supporting software pose significant barriers to implementing STEM. Universities need to prioritize investments in standardized practice rooms equipped with advanced technology, such as 3D printers and engineering simulation software. Collaborating with technology companies for sponsorship or equipment provision can alleviate financial pressures and ensure students have a practical learning environment.

Developing Flexible and Interdisciplinary Curricula: Current curricula in many Vietnamese universities are rigid and lack integration between subjects. To effectively implement STEM, universities should design flexible curricula that encourage students to participate in interdisciplinary projects, where they can apply knowledge from multiple fields to solve real-world problems. Courses should be developed to integrate theory with practice, enhancing engagement and effectiveness.

Strengthening Collaboration with Businesses and Communities: A significant challenge is the gap between theoretical education and the practical needs of the labor market. Universities should collaborate closely with businesses to develop STEM projects aligned with real-world applications, providing students with opportunities for internships or solving actual industry problems. Additionally, organizing competitions, STEM exhibitions, or community programs will stimulate creativity and motivate student learning.

Changing Mindsets and Encouraging Creative Thinking: Many students and faculty hesitate to embrace STEM due to a lack of confidence or passive mindsets. Universities should promote the benefits of STEM through seminars and discussions to shift perceptions. Furthermore, encouraging students to engage in creative activities, such as product development or joining STEM clubs, will foster innovative thinking and teamwork skills.

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DISCUSSION

DATA ANALYSIS ON STEM EDUCATION

STEM Data Search Process in Higher Education

The search process is as follows:

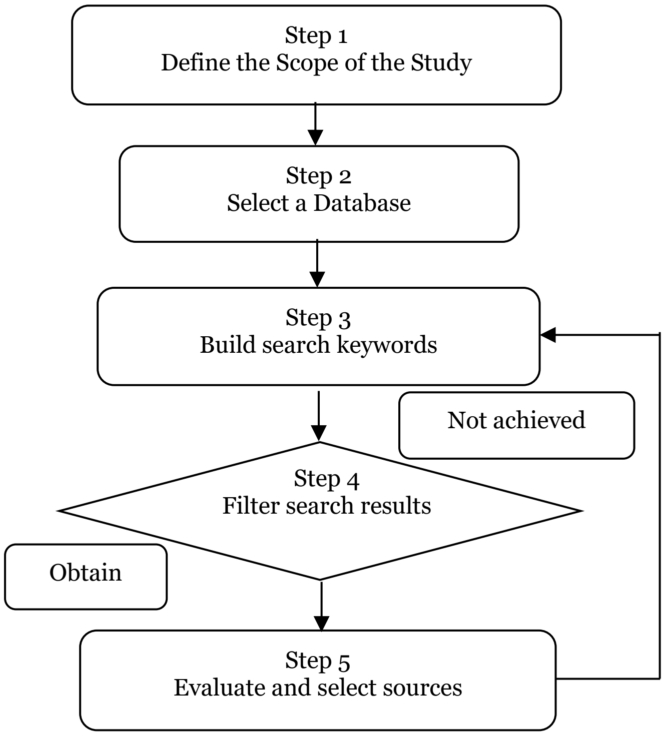

Figure 1. Data Search Process

Step 1. Define the Scope of the Study

The scope of research on higher education STEM education includes many important aspects. First, research focuses on developing integrated, interdisciplinary training programs that meet labor market needs. Second, exploring and applying active teaching and learning methods, while integrating information technology. Third, research focuses on building comprehensive STEM competency assessment tools. Fourth, research on training and fostering STEM lecturers.

Step 2. Select a Database

Selecting a database for undergraduate STEM education research requires careful consideration. Databases such as Scopus, Web of Science, and ERIC provide scholarly articles, journals, and research papers relevant to undergraduate STEM education. In addition, discipline-specific databases such as IEEE Xplore and ACM Digital Library can be useful for technology and engineering research. Additionally, Google Scholar is a multidisciplinary search engine that provides access to a wide range of literature. Choosing the right database will ensure the accuracy and reliability of your research.

Step 3. Build search keywords

To develop effective search keywords for the topic of university-level STEM education, it is necessary to clearly identify the research aspects. General keywords such as "university STEM education" and "university STEM training" are good starting points. Next, focus on specific areas such as "university STEM programs", "STEM teaching methods", "STEM competency assessment", "STEM faculty development" and so on.

Step 4. Filter search results

To filter search results effectively, first limit your search by using specific keywords and combine them with Boolean operators (AND, OR, NOT). Next, use filters by document type (article, book, report), publication date (e.g., select only articles from the last 10 years), and language. If using specialized databases, take advantage of filters by field of study, author, and journal. Finally, evaluate the credibility of the source by considering the reputation of the author, journal, and publisher.

Step 5. Evaluate and select sources

It is necessary to clearly define the research objectives in order to select appropriate sources. Scientific articles from reputable journals such as "Journal of Engineering Education" or "International Journal of STEM Education" are reliable sources of information. In addition, reports from educational organizations such as UNESCO or OECD provide an overview of STEM education trends. Monographs from academic publishers are also valuable references. It is necessary to evaluate the reliability of the source based on the author, publisher, and citation. Finally, combine different types of sources to have a comprehensive view of the topic.

Number of articles and research works

Scopus and ERIC databases are two major scientific databases in the field of educational research that have been used for online searching (Figure 2). Among them, Scopus can be considered one of the most prestigious academic databases that only includes quality journals that meet international criteria, are peer-reviewed and recognized in the scientific community (Tober, 2011). In addition, Google Scholar database was used to search for additional studies, focusing on the first 200 to 300 results displayed (Haddaway et al., 2015).

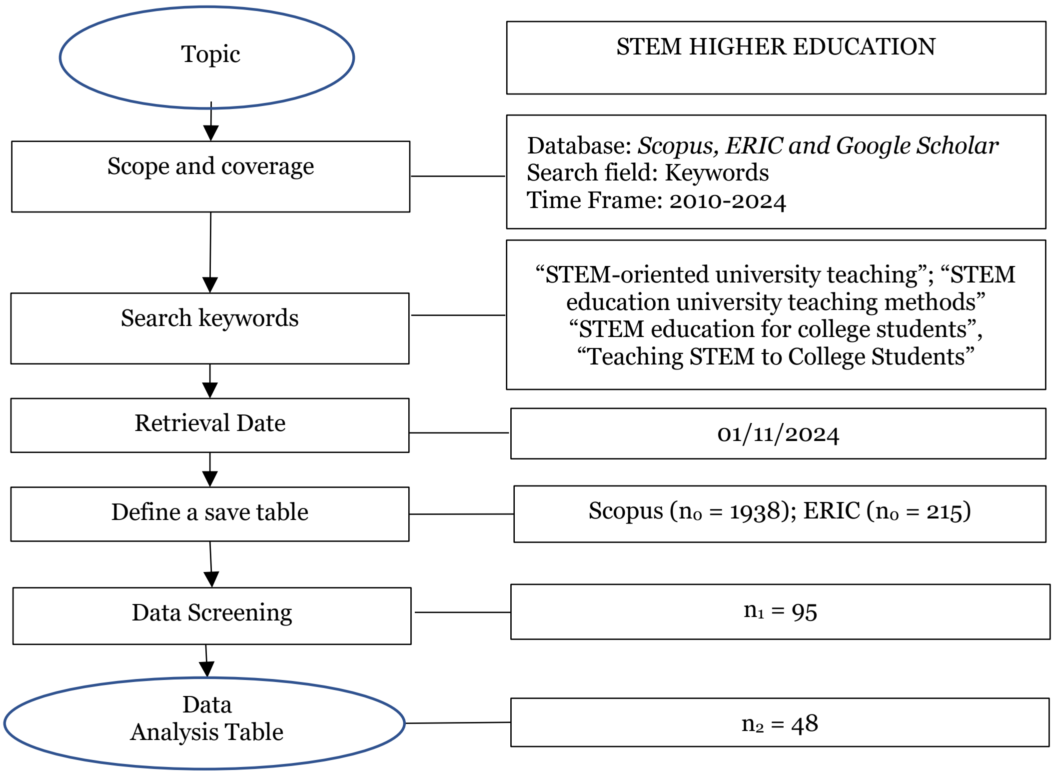

Figure 2. Schematic diagram of STEM search data analysis in higher education

As shown in Figure 2, the selection of studies for the systematic review was carried out in four stages: identification, screening, eligibility, and included studies. The first analysis stage was a search of data in Scopus and ERIC in November 2024. This resulted in 2,135 results, with 1,938 results in Scopus and 215 results in ERIC. In addition, the first 268 results of Google Scholar searches were also screened, resulting in 18 additional articles. In the second analysis stage, the data were transferred to Mendeley software for duplicate checking, resulting in 74 studies being removed. In the third analysis stage, the remaining 2,079 articles were screened by reviewing the title, abstract, and

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keywords. In the third stage, 1,984 studies were excluded because they did not meet the following criteria: The studies were peer-reviewed and published in reputable scientific journals; The studies were published in English; The participants were undergraduate students. In the fourth stage, a total of 95 potentially eligible studies were retained for full-text screening. A study quality assessment criterion designed by Margot and Kettler was used to evaluate the full-text studies in terms of (1) aims and objectives, (2) literature review, (3) theoretical framework, (4) participants, (5) methods, (6) results and conclusions, and (7) implications. Each of the seven criteria was scored on a 4-point scale where 1 = Does not meet the criteria, 2 = Nearly meets the criteria, 3 = Meets the criteria, and 4 = Exceeds the criteria (Margot & Kettler, 2019). Articles with a total score equal to or less than 14 points were excluded (Margot & Kettler, 2019). After assessing the quality of the studies, 48 studies were excluded and 48 studies were retained for inclusion in the literature review.

The number of articles and research works on STEM education at the university level is currently limited. After conducting the search and screening process, only 48 studies related to STEM for higher education were found. These publications were mainly published in prestigious educational and scientific journals in the world. This shows that STEM in university teaching is a topic of interest and plays an important role in the educational reform process in Vietnam.

Table 1. Research related to STEM higher education

TT	Topic	Research content
1	Innovative teaching methods	Innovative teaching methods in undergraduate STEM education, such as active learning and co-teaching, enhance student engagement and critical thinking (Apkarian et al., 2021; Haag et al., 2023). Integrating digital technologies and AI fosters knowledge co-creation (Reyna & Meier, 2020; Hasan & Khan, 2023). Teaching with primary scientific literature deepens research understanding (Goudsouzian & Hsu, 2023). However, implementing these methods in Vietnam is constrained by resources and training (Huong et al., 2021). Adapting these pedagogies to Vietnam's educational context, especially at universities like Hanoi University of Science and Technology, is essential to improve STEM education effectiveness and prepare students for a tech-driven economy.
2	Curriculum Development and Integration	Another key theme is the development of undergraduate STEM curricula that are relevant to the current and future context. This involves designing highly interdisciplinary programs (Gao et al., 2020; Margot & Kettler, 2019), ensuring inclusivity and accessibility for all students (Schreffler et al., 2019; Batty & Reilly, 2023), as well as integrating real-world elements and challenges into the learning process (Bhatti, 2024).
3	Inclusion and Equity in STEM	Inclusivity in undergraduate STEM education ensures opportunities for students with disabilities and minorities through Universal Design for Learning and inclusive pedagogy (Schreffler et al., 2019; Valdez & Kelp, 2023). Community projects promote social justice (Vance-Chalcraft et al., 2024). In Vietnam, cultural diversity necessitates inclusive STEM programs, but awareness and resources are limited (Huong et al., 2021; Batty & Reilly, 2023). Developing inclusive models tailored to Vietnam's context is essential to enhance student participation and success, particularly in rural areas, fostering equitable STEM education that supports diverse learners and aligns with global standards.
4	Professional Development for Instructors	Faculty professional development is key to enhancing undergraduate STEM education. Discipline-based training enables faculty to adopt innovative methods (Manduca et al., 2017; Gehrtz et al., 2022). STEM centers support teaching transformation (Carlisle & Weaver, 2018). In Vietnam, faculty training lacks scale and continuity (Huong et al., 2021). Multi-institutional

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		networks can drive innovation (Santangelo et al., 2021). Designing tailored training programs is crucial to boost STEM faculty capabilities, especially at institutions like Vietnam National University, ensuring they implement evidence-based teaching to prepare students for a global workforce.
5	Change and Improvement in STEM Education	Undergraduate STEM education is constantly evolving and requires continuous change and improvement to meet new challenges and opportunities. Research in this theme focuses on identifying the drivers and barriers to innovation (Beach et al., 2012; Henderson et al., 2011), the role of STEM education centers (Carlisle & Weaver, 2018; Coleman et al., 2019; Santangelo et al., 2021), and the effectiveness of professional development programs for faculty (Manduca et al., 2017; Winberg et al., 2018).

Keyword Network

The STEM Keyword Network in Higher Education is a useful tool for exploring research trends, identifying priority areas, and developing effective STEM education development strategies.

To construct a network of higher education STEM, first identify the main keywords for data searching. Use the keywords: "college STEM programs", "college STEM teaching methods", "college student STEM competencies", and "college STEM education assessment". These keywords can also be combined with "STEM interdisciplinary integration", "STEM educational technology", or "STEM faculty development" to narrow the search scope and find the most relevant information.

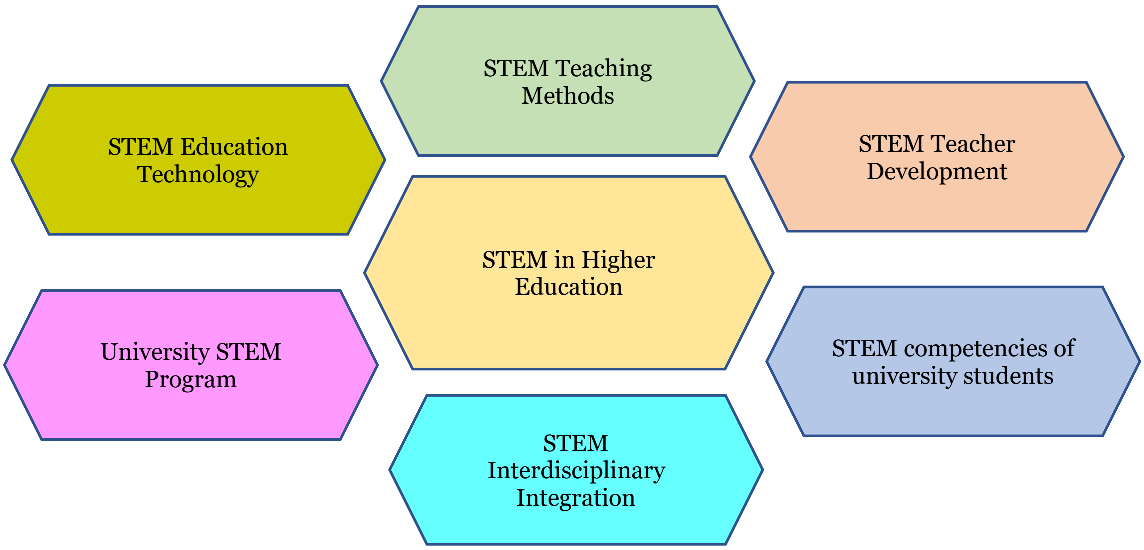

Figure 3. Data Keyword Search Diagram

After searching for data on higher STEM education, proceed to build a data network diagram using VOSviewer software.

The VOSviewer keyword network on higher education STEM in the figure above shows the diverse connections between concepts. The center of the network is "stem field" and "higher education institution", showing the close relationship between STEM and higher education. Keywords such as "math", "teaching practice", "pedagogical approach" and "experimental learning" reflect teaching and learning methods in STEM education. The network also emphasizes the roles of "engineer", "college student", "university student", "graduate student" and "stem student", showing the focus on learners. "Research method", "case study", "simulation" and "learning experience" are important research and learning methods. "Industry" and "engineering programs" show the connection between

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STEM education and industry. The network provides an overview of different aspects of higher STEM education, from teaching methods to the role of learners and links with industry.

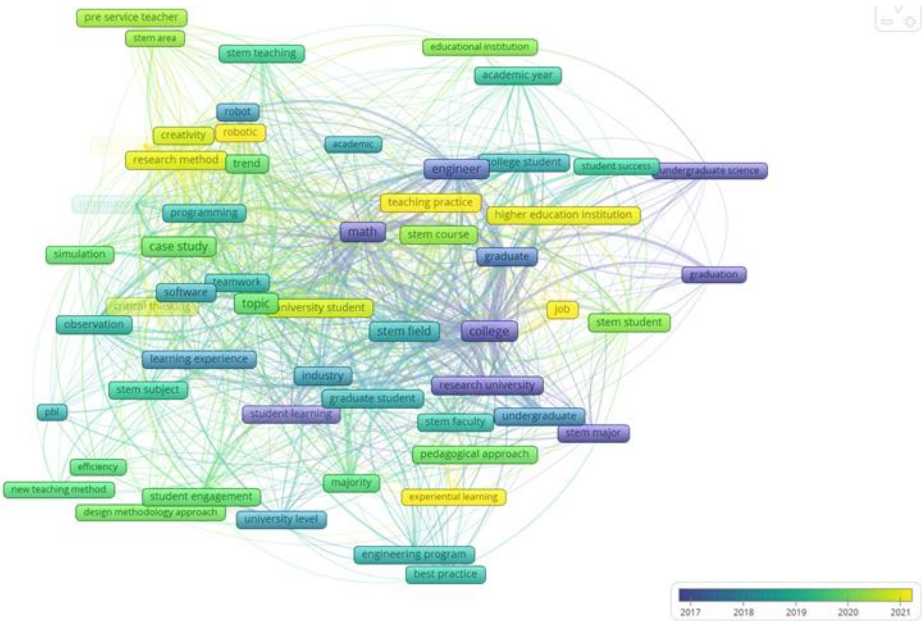

Figure 4. Keyword Network Diagram for Higher Education STEM

Author Network

The Higher STEM Education Author Network represents research collaboration. This network shows the interconnectedness of authors, reflecting interactions and collaborations in the field of higher STEM education.

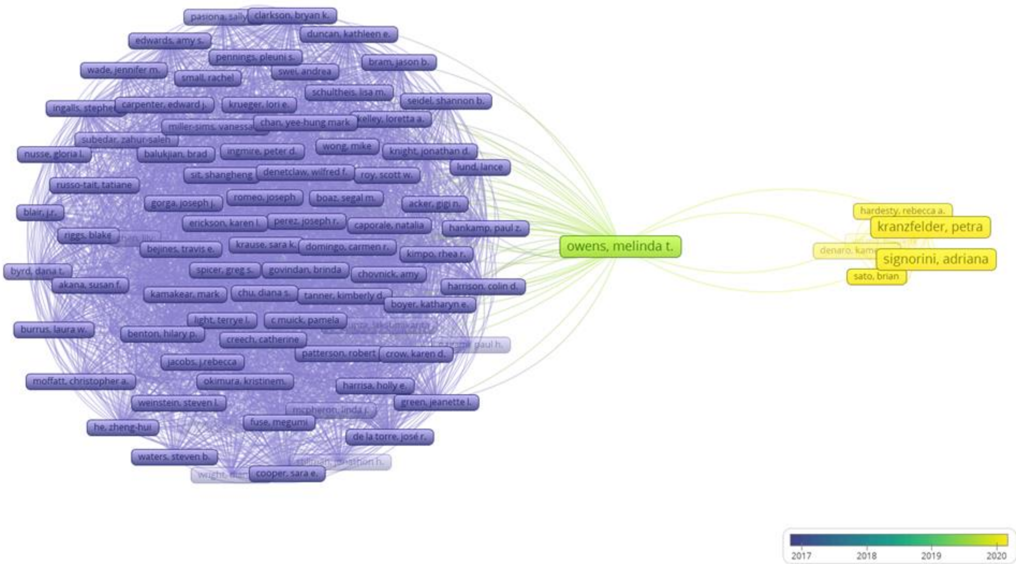

Figure 5. Author Network of STEM Education Research for Undergraduate Students

The VOSviewer author network on higher education STEM in the figure above shows a diverse and closely connected research community. The largest group of authors, represented by the dark purple cluster, shows a wide and diverse collaboration. The authors in this group have many connections to each other, indicating close collaboration on research projects.

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A smaller group of authors, represented by the light yellow cluster, shows more dispersion. The author "owens, melinda t" plays a central role in this group, connecting with the authors "kranzfelder, petra" and "signorini, adriana". This suggests that "owens, melinda t" may be an influential researcher in the field.

The network also shows the time distribution of the studies. Authors in the dark purple group had more studies published between 2017 and 2020, while authors in the light yellow group had more studies published between 2020 and 2021. This shows the growth and change of the field of higher education STEM research over time.

Research Gaps

To identify the research gap, the authors carefully collected and screened relevant scientific documents. Then, they read and analyzed each document in depth, focusing on the objectives, methods, results, and discussion. This process included comparing and contrasting the findings to identify trends, contradictions, and open issues. Special attention was paid to the "Recommendations for Future Research" section. By systematically synthesizing and evaluating the existing evidence, the authors identified unanswered questions or aspects that had not been fully explored, thereby forming a research gap.

Lack of Research on Inclusivity

Although inclusivity in STEM education is emphasized, specific studies on practically implementing inclusive strategies and their effectiveness for underrepresented groups, such as students with disabilities or minorities, are lacking (Batty & Reilly, 2023; Valdez & Kelp, 2023). The literature does not fully evaluate these strategies' impact on participation and academic achievement in STEM courses (Schreffler et al., 2019). Further research is needed to develop effective inclusive models, ensuring equitable opportunities for all students to succeed in diverse STEM environments.

Application of New Technologies

Research on applying new technologies, such as AI and online learning tools, in STEM teaching is limited, particularly regarding their impact on pedagogy and student learning (Hasan & Khan, 2023). The literature does not fully explore how technologies like virtual reality or MOOCs can be effectively integrated into STEM courses (Reyna & Meier, 2020). Further research is needed to evaluate these technologies' potential to enhance teaching quality and improve learning outcomes in STEM education.

Long-Term Research on Engagement Impact

Long-term studies on the impact of active learning methods on STEM student engagement and knowledge retention post-graduation are lacking (Cromley et al., 2016). The literature does not fully assess how these methods shape STEM careers or sustain professional skills over time (Apkarian et al., 2021). Further research is needed to understand the lasting effects of active learning on career development and the application of STEM knowledge post-graduation.

Influence of Culture and Context

The influence of sociocultural and local contexts on access and success in STEM education is understudied (Gao et al., 2020). The literature lacks in-depth analysis of how cultural factors affect student participation in institutions with diverse backgrounds (Barlow & Brown, 2020). Further research is needed to explore how these factors shape the effectiveness of STEM programs, particularly in diverse settings.

Faculty Training Strategies

Research on training faculty to adopt modern STEM teaching methods is limited, particularly on designing effective training programs (Henderson et al., 2011). The literature does not fully explore long-term training strategies to support faculty innovation (Manduca et al., 2017). Further research is needed to develop training models that enable STEM faculty to integrate advanced pedagogies, enhancing teaching quality.

Assessment of Post-Course Skills

Research on assessing soft skills, such as critical thinking and teamwork, after completing STEM courses is lacking (Reynders et al., 2020). The literature does not fully evaluate how these skills are sustained or applied in professional settings (Cromley et al., 2016). Further research is needed to develop effective assessment methods to measure the long-term development of soft skills in STEM.

Role of Community and Social Interaction

The role of community collaboration programs and practical experiences in enhancing STEM engagement and career development is understudied (Santangelo et al., 2021). The literature lacks in-depth analysis of how social interactions influence student motivation and success (Vance-Chalcraft et al., 2024). Further research is needed to evaluate the impact of community initiatives on STEM career development.

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