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# Exploring Integrated STEM Teaching Practices: A Bibliometric Analysis of the Literature

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**Abstract:** *This bibliometric analysis explores the evolving research landscape of integrated Science, Technology, Engineering, and Mathematics (STEM) teaching, focusing on publication trends, influential authors, and key areas of study. As STEM education gains importance globally, there is a need to understand how integrated STEM teaching is being developed and researched, which this study addresses through a systematic examination of publications indexed in Scopus. The analysis identifies gaps in existing literature, particularly in specialized aspects of integrated STEM that require further exploration. Using Scopus Analyzer and VOSviewer software, data from 1,142 relevant publications were extracted and analyzed to reveal publication trends, keyword co-occurrences, and collaborative networks among authors and countries. Results indicate a notable increase in publications after 2018, reflecting heightened interest and investment in STEM education research. Key findings reveal that research in this field is centered around themes like student engagement, instructional methods, curriculum development, and teacher training, with keywords such as "students," "teaching," and "STEM education" frequently occurring. The United States leads in publication volume and global collaboration, with significant contributions also observed from countries like China, Australia, and the United Kingdom. Citation analysis highlights several influential authors whose work has shaped the field, particularly in areas of instructional strategy and computational thinking. Overall, this study provides insights into the main research trends, influential contributors, and emerging topics in integrated STEM education, offering a foundation for future research to address remaining gaps and further enhance STEM teaching methodologies.*

**Keywords:** integrated STEM, teaching, pedagogy

## 1. Introduction

Integrating Science, Technology, Engineering, and Mathematics (STEM) into educational practices has garnered significant attention due to its potential to enhance student learning outcomes and interest in these fields. Moreover, integrated STEM education aims to create a more cohesive learning experience by connecting these disciplines through real-world applications and problem-solving activities. Research indicates that integrated STEM approaches can improve students' engagement, motivation, and higher order thinking skills, making it a promising practice for modern education (Hamad et al., 2022; Struyf et al., 2019; Thibaut, Ceuppens, et al., 2018). However, implementing integrated STEM is not without

challenges, as it requires a shift in instructional practices and the development of new teaching materials and strategies (Fan et al., 2020; Stohlmann et al., 2012).

One of the primary benefits of integrated STEM education is its ability to make learning more relevant and engaging for students. By incorporating real-world problems and design-based learning, students can see the practical applications of their studies, increasing their interest and motivation in STEM subject (Le et al., 2023; Struyf et al., 2019). Additionally, integrated STEM education promotes collaborative learning and critical thinking as students work together to solve complex problems and develop innovative solutions (Thibaut, Ceuppens, et al., 2018; Thibaut et al., 2019). Despite these advantages, teachers often face obstacles such as a lack of time, insufficient resources, and the need for professional development to implement integrated STEM practices effectively (Hamad et al., 2022; Stohlmann et al., 2012).

To address these challenges, researchers have developed various frameworks and models to guide the implementation of integrated STEM education. These frameworks emphasize the importance of content integration, problem-centred learning, and inquiry and design-based activities to foster a deeper understanding of STEM concepts (Fan et al., 2020; Thibaut, Ceuppens, et al., 2018). Moreover, professional development and support for teachers are crucial for successfully adopting integrated STEM practices, as they help educators build the necessary skills and confidence to navigate this instructional approach (Stohlmann et al., 2012; Thibaut et al., 2019). By addressing these challenges and leveraging the benefits of integrated STEM education, schools can better prepare students for future careers in STEM fields and contribute to national development (Juškevičienė et al., 2021; Yaki et al., 2019).

## 2. Literature Review

In recent years, the integration of STEM education has gained significant attention due to its potential to enhance student outcomes and prepare them for future challenges. The concept of integrated STEM teaching emphasizes the interconnectedness of these disciplines, aiming to improve students' critical thinking, problem-solving abilities, and motivation to learn. As the demand for STEM-related skills grows in the workforce, educational strategies must evolve to equip students with the knowledge and competencies required to address complex, real-world problems. This literature review examines the current research on integrated STEM education, focusing on teacher preparation, curriculum development, innovative teaching methods, and the challenges in implementation.

Recent research underscores the importance of integrated STEM education in enhancing student motivation and learning outcomes. For instance, Reiser et al., (2024), discovered that design-based STEM programs significantly boosted students' motivation compared to traditional teaching methods, with cognitive abilities and prior motivation emerging as key predictors of success. Teacher preparation also plays a critical role, as evidenced by Love & Hughes (2022), who revealed that formal and informal preparation experiences significantly impacted educators' ability to teach STEM content effectively. These findings highlight the need for robust teacher training programs that develop educators' Pedagogical Content Knowledge (PCK) in STEM subjects, especially engineering.

Note that curriculum development remains a crucial area of focus in integrated STEM education. Studies have shown that well-designed integrated STEM curricula positively impact student learning outcomes. For example, Anwar et al. (2022) demonstrated that a STEM unit improved sixth-grade students' understanding of ecological concepts and engineering design

while enhancing their knowledge retention. Moreover, Shahali & Halim, (2024) examined how teacher beliefs, self-efficacy, attitudes, and school context shape STEM teaching practices. These findings suggest that addressing contextual factors in curriculum design and teacher training can improve the effectiveness of integrated STEM instruction, ensuring alignment with educational goals.

Despite the progress, significant challenges remain in implementing integrated STEM education effectively. Teachers often face tensions between disciplinary content and integrated learning, as highlighted by Dubek et al., (2024) who noted the difficulty in balancing skills development with content knowledge. In the context of Chinese education, Lyu et al. (2022) identified challenges such as varying teacher experiences and a lack of tailored professional development to address the complexities of STEM integration. These findings emphasize the need for context-specific support systems that help teachers navigate the challenges of implementing integrated STEM education in diverse educational settings.

Innovative teaching methods, such as Augmented Reality Learning Environments (ARLEs), show great potential in enhancing STEM education. For example, Li et al., (2024) demonstrated that ARLEs significantly improved students' mathematics self-efficacy and comprehension of complex scientific concepts like kinematics by encouraging exploration and interaction. Similarly, Boltsi et al. (2024) explored the application of Education 4.0 principles and digital tools, such as Internet of Things (IoT) and smart sensors, to build students' digital competencies and prepare them for interdisciplinary problem-solving. Additionally, Menke et al. (2024) highlighted how collective argumentation in elementary STEM education promotes critical thinking, knowledge construction, and diverse perspectives, showcasing the importance of collaborative and innovative approaches in STEM learning.

Another significant trend in STEM education is the integration of culturally sustaining pedagogies. Tran & Selcen Guzey (2023) show how these approaches, particularly in middle school science and engineering classrooms, validate students' lived experiences and support alternative epistemologies that challenge traditional STEM knowledge hierarchies. Similarly, Ismail et al. (2024) addresses the challenges faced by Malaysian secondary science teachers in connecting STEM disciplines effectively, noting that teachers often struggle with interdisciplinary integration despite efforts to adopt inquiry-based and problem-based learning methods. This gap highlights the need for continuous professional development and stronger collaborative efforts to enhance teaching practices in STEM education.

Therefore, addressing contextual challenges and fostering collaborative STEM instruction remain critical priorities. For instance, Han et al. (2023) determined that engineering design-based models provide students in rural areas with valuable interdisciplinary problem-solving opportunities. However, success depends on adequate resources and teacher training. Similarly, Burrows et al. (2021) revealed that professional development programs for pre-collegiate educators in the US improved STEM content knowledge but required additional time for teachers to apply this knowledge effectively in classrooms. Furthermore, structured professional development models, such as the Lesson Study Model (LSM) adapted for distance education during the COVID-19 pandemic, enhanced educators' pedagogical and content knowledge Aykan & Yıldırım (2022). These studies underscore the importance of sustained support, tailored teacher training, and innovative teaching methods to implement integrated STEM education across diverse contexts successfully.

## 3. Research Question

1) What are the research trends in integrated STEM teaching according to the year of publication?
2) Who writes the most cited articles, and where do they work?
3) Who are the top ten authors based on citation by research?
4) What are the popular keywords related to the study?
5) What are co-authorship countries' collaboration?

## 4. Methodology

Bibliometrics refers to the combination, management, and analysis of bibliographic information extracted from scientific publications (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). This approach includes basic descriptive data, such as the journals where studies are published, the publication years, and the primary authors (Wu & Wu, 2017). It also encompasses more complex methods, like document co-citation analysis. A successful literature review requires an iterative approach—identifying relevant keywords, performing a literature search, and conducting in-depth analyses to build a solid bibliography and derive reliable insights (Fahimnia et al., 2015). Given these requirements, this study focuses on top-tier publications, as they provide valuable perspectives on the theoretical underpinnings driving research in the field. To ensure data reliability, the study exclusively used the Scopus database for data collection (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). Further, only articles published in rigorously peer-reviewed academic journals were included to maintain a high-quality standard, deliberately excluding books and lecture notes (Gu et al., 2019). With its extensive coverage, Elsevier's Scopus gathered publications for analysis from 2020 through December 2023.

### 4.1 Data Search Strategy

The study used a screening sequence to identify the search phrases for article retrieval. The study began by querying the Scopus database with online TITLE (integrated AND stem AND (teach* OR pedagogy), assembling 1596 articles. The final search string is shown in Table 1. The refinement contained 1142 articles, which were used for bibliometric analysis. As of November 2024, all publications from the Scopus database relevant to integrated STEM teaching practice were included in the study.

**Table 1: The research string**

| | |
|---|---|
| **Scopus** | TITLE-ABS-KEY ( integrated AND stem AND ( teach* OR pedagogy ) ) AND PUBYEAR > 2014 AND PUBYEAR < 2025 AND ( LIMIT-TO ( LANGUAGE , "English" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) |

**Table 2: The selection criterion is searching**

| Criterion | Inclusion | Exclusion |
|---|---|---|
| **Language** | English | Non-English |
| **Timeline** | 2015 – 2024 | < 2015 |
| **Literature type** | Journal (Article) and proceeding | Book, Review |

Table 2 presents that the selection criteria for this study are focused on ensuring relevant and up-to-date literature. Only studies published in English from 2015 to 2024 are included, while those published before 2015 or in languages other than English are excluded. Additionally, only journal articles and conference proceedings are considered, while books and review

articles are excluded. This approach ensures that the selected literature is current, accessible, and directly related to the topic of study, providing a more accurate representation of recent developments in the field.

### 4.2 Data Analysis

VOS-viewer is a user-friendly and robust bibliometric software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (Appio et al., 2014; van Eck & Waltman, 2017). It is widely used for visualizing and analysing scientific literature, with its capabilities extending to creating intuitive network visualizations, clustering related items, and generating density maps. Moreover, VOS-viewer is highly versatile, allowing researchers to examine co-authorship, co-citation, and keyword co-occurrence networks, enabling a comprehensive understanding of research trends and connections. The tool's interactive interface and regular updates facilitate efficient exploration of large datasets, making it an invaluable resource for scholars seeking insights into complex research domains.

One of the standout features of VOS-viewer is its ability to convert complex bibliometric datasets into visually interpretable maps and charts. The software excels at clustering related items, analysing keyword co-occurrence patterns, and generating detailed network visualizations. Its user-friendly interface makes it accessible to novice and experienced users, allowing them to explore research landscapes easily. With continuous development, VOS-viewer remains at the forefront of bibliometric analysis, providing valuable insights through customizable visualizations and metrics computations. Its ability to handle various types of bibliometric data, such as co-authorship and citation networks, makes it a versatile and essential tool for researchers seeking deeper insights within their fields.

In this study, bibliometric datasets were collected from the Scopus database, spanning the period from 2020 to December 2023, and containing publication year, title, author names, journal details, citations, and keywords in Plaintext format. These datasets were analysed using VOS-viewer software (version 1.6.19). Through VOS clustering and mapping techniques, the software facilitated the examination and creation of visual representations. Unlike the Multidimensional Scaling (MDS) approach, the VOS-viewer places items within low-dimensional spaces, ensuring that the proximity between any two items accurately reflects their relatedness and similarity (van Eck & Waltman, 2010). While MDS primarily relies on similarity metrics such as cosine and Jaccard indices, VOS-viewer employs a more suitable method for normalizing co-occurrence frequencies, using the Association Strength (ASij) calculation (Van Eck & Waltman, 2007), which better represents item relationships:

$$AS_{ij} = \frac{C_{ij}}{W_i W_j} \quad ,$$

which is proportional to the ratio between the observed number of co-occurrences of *i* and *j* and the expected number of co-occurrences of *i* and *j* under the assumption that co-occurrences of *i* and *j* are statistically independent (van Eck & Waltman, 2010). VOS-viewer utilizes a specific index to map items by reducing the weighted sum of squared distances between all item pairs. This approach enables the software to represent the data in an intuitive visual format. Consequently, (Appio et al., 2014) notes that the VOS-viewer employs the LinLog/modularity normalization method to refine the data mapping process further. By applying these visualization techniques, the VOS-viewer uncovers patterns rooted in mathematical relationships, allowing for comprehensive analyses, including keyword co-occurrence, citation analysis, and co-citation analysis. These methods help researchers understand the connections

and trends within the dataset more clearly, offering insights into a research domain's evolution and focus areas.

Applying specific analyses provides a deeper understanding of the development of research topics over time. For instance, keyword co-occurrence analysis is instrumental in identifying emerging trends and popular topics within a field (Zhao et al., 2017), while citation analysis helps uncover key research issues, trends, and methodologies, shedding light on the historical development of a discipline. Document co-citation analysis, one of the most used bibliometric methods, plays a crucial role in identifying the underlying structure of research networks. This analysis relies on network theory to map the relationships and relevance between documents, as demonstrated by studies such as those by (Appio et al., 2014; Fahimnia et al., 2015). When applied through VOS-viewer, these techniques provide a robust framework for exploring scholarly communication and research development complexities.

## 5. Finding and Discussions

### 5.1 RQ1: What are the research trends in integrated STEM teaching according to the year of publication?

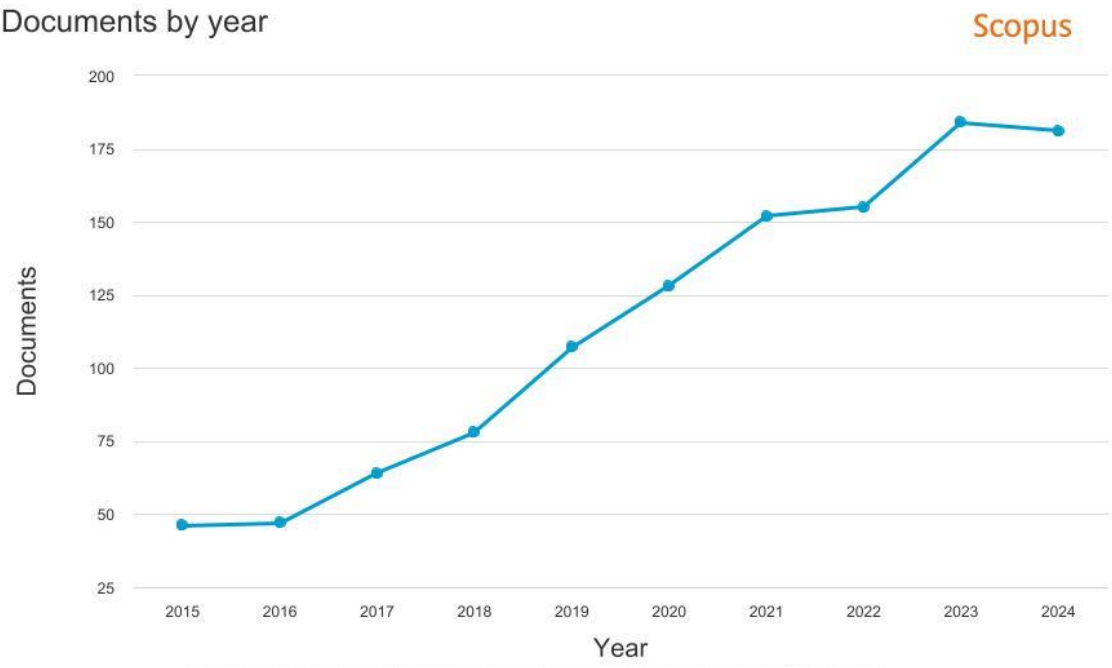


**Figure 1: Plotting trends in integrated STEM teaching according to the year of publication**.

The trend in the figure indicates a significant growth in publications on the topic of integrated STEM teaching practice over the past decade. From 2015 to 2018, the number of documents remained relatively low, with fewer than 75 publications annually, suggesting that interest in this field was still emerging. However, starting in 2018, a noticeable upward trend was observed, reflecting a growing recognition of the importance of STEM integration in education. This rise in publication numbers may also correspond to increased research funding, policy support, and initiatives to strengthen STEM education globally. The gradual increase from 2018 onward likely aligns with the implementation of STEM programs in educational institutions, encouraging further academic discourse and research.

By 2022, the annual publication count had crossed 150, indicating that integrated STEM teaching practices had become an established area of interest in educational research. This upward trajectory continues into 2023, although it shows a slight plateau by 2024, potentially suggesting a phase of stabilization as the research field matures. Consequently, this plateau might be attributed to a saturation point in foundational research or a shift in research focus toward more specific aspects within integrated STEM education. Overall, this growth trajectory illustrates how integrated STEM teaching has evolved from a nascent field to a prominent area of study, reflecting both global educational priorities and the sustained interest of researchers in developing effective, interdisciplinary teaching practices in STEM fields.

### 5.2 RQ2: Who writes the most cited articles, and where do they work?

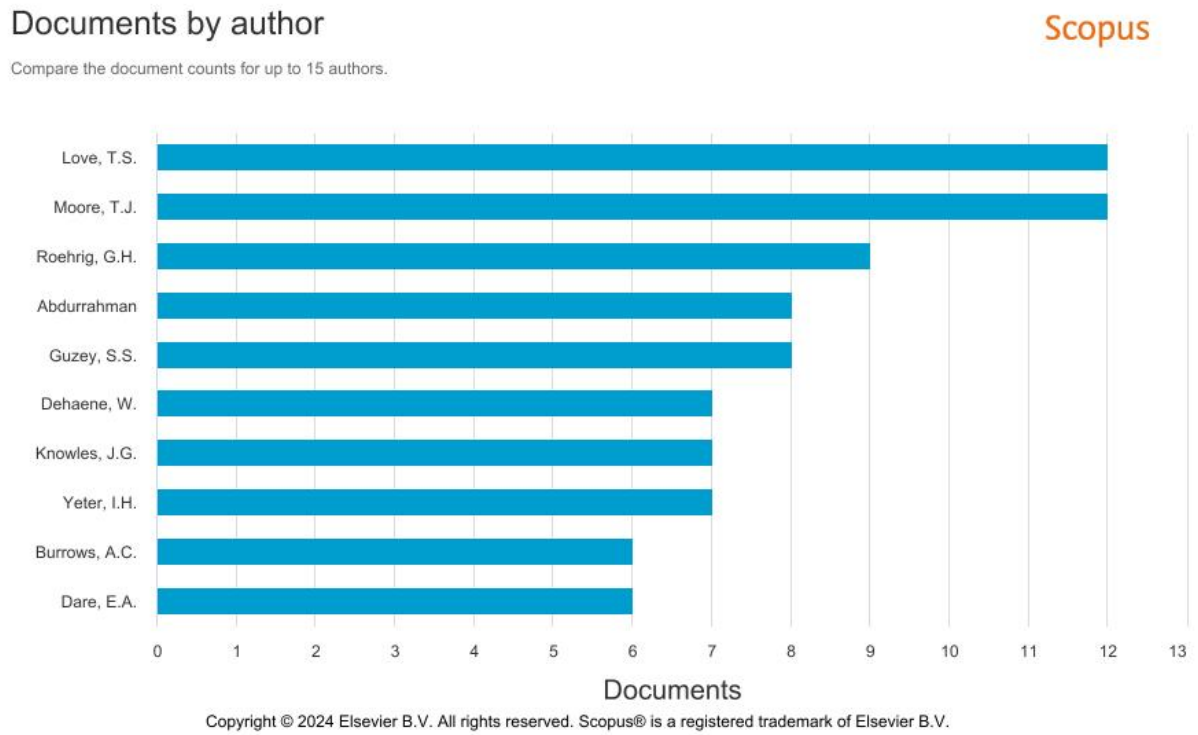


**Figure 2: Plotting the most cited articles by author.**

The chart presents the top authors contributing to integrated STEM teaching practice, with a notable concentration of publications from a few leading researchers. Love, T.S. and Moore, T.J. have the highest output, each with approximately 12 publications, positioning them as prominent figures in this domain. This suggests they may have significantly contributed to foundational theories, methodologies, or program implementations within integrated STEM education. Following them, Roehrig, G.H., and Abdurrahman have contributed around nine and eight documents, respectively, which also positions them as influential voices in the field. Their work likely supports or builds upon the foundational research provided by the leading authors, furthering the field's development and understanding.

The remaining authors, such as Guzey, S.S., Dehaene, W., and Knowles, J.G., have each contributed around six to seven publications, which still represent a substantial commitment to the field. Their research contributions may involve specialized studies or innovative approaches that address specific challenges in STEM education, such as curriculum design, instructional strategies, or educational technologies. Note that the diversity of authors and their

contributions reflect a collaborative effort to advance STEM integration in education, with each researcher adding unique insights. This diversity also highlights the multidimensional nature of integrated STEM education, which requires inputs from varied perspectives to address complex educational needs effectively.

**Table 3: The top 10 authors contributing to research on integrated STEM teaching by number and percentage of documents.**

| Author Name | Number of Document | Percentage |
|---|---|---|
| Love, T.S. | 12 | 1.051 |
| Moore, T.J. | 12 | 1.051 |
| Roehrig, G.H. | 9 | 0.788 |
| Abdurrahman | 8 | 0.701 |
| Guzey, S.S. | 8 | 0.701 |
| Dehaene, W. | 7 | 0.613 |
| Knowles, J.G. | 7 | 0.613 |
| Yeter, I.H. | 7 | 0.613 |
| Burrows, A.C. | 6 | 0.525 |
| Dare, E.A. | 6 | 0.525 |

The bibliometric analysis reveals the top 10 authors contributing to research on integrated STEM teaching practices. Love, T.S., and Moore, T.J. lead the list, each authoring 12 documents, accounting for 1.051% of the total. This significant contribution suggests their prominent roles in advancing STEM education research, likely positioning them as influential voices in shaping STEM pedagogy and practices. Their work may include comprehensive studies or the development of theoretical frameworks integral to STEM teaching.

Next, authors such as Roehrig, G.H., and Abdurrahman follow, contributing nine and eight documents, respectively, with slightly lower percentages. These authors also demonstrate a strong research presence in STEM education. The clustering of authors contributing a comparable number of documents highlights a collaborative and competitive research environment where a network of academics drives the field forward. Moreover, these authors' relatively high document count suggests ongoing engagement and possibly collaborative projects.

Lastly, the data shows a more distributed contribution among the remaining authors, including Guzey, S.S., Dehaene, W., and Knowles, J.G., each contributing between 6 to 8 documents. This range indicates a healthy diversity of perspectives, enriching the field through various thematic focuses or methodologies. These authors' involvement highlights the growing complexity and depth of STEM teaching practices, addressing diverse aspects such as curriculum integration, student engagement, and pedagogical innovation. This distributed authorship underlines the interdisciplinary nature of STEM education research, which is essential for its evolution.

### 5.3 RQ3: Who are the top 10 authors based on citation by research?

Table 4 presents the citation analysis of the top 10 most-cited works in integrated STEM teaching, highlighting the significant contributions of key studies to the field, showcasing a focus on teacher preparation, instructional practices, and curriculum development.

**Table 4: The top 10 authors based on citation by research journal and year of publication.**

| Authors | Title | Year | Journal | Cited by |
|---|---|---|---|---|
| Corlu et al. (Corlu & Capraro, 2014) | Introducing STEM Education: Implications for Educating Our Teachers For the Age of Innovation | 2014 | Education and Science Journal | 156 |
| Kelley et al. (Kelley et al., 2020) | Increasing high school teachers' self-efficacy for integrated STEM instruction through a collaborative community of practice | 2020 | International Journal of STEM Education | 117 |
| Thibaut et al. (Thibaut et al., 2018) | The influence of teachers' attitudes and school context on instructional practices in integrated STEM education | 2018 | Teaching and Teacher Education | 104 |
| Chalmers C. (Chalmers, 2018) | Robotics and computational thinking in primary school | 2018 | International Journal of Child-Computer Interaction | 166 |
| Guzey et al. (Guzey et al., 2016) | Building Up STEM: An Analysis of Teacher-Developed Engineering Design-Based STEM Integration Curricular Materials | 2016 | Journal of Pre-College Engineering Education Research | 112 |
| Ring et al. (Ring et al., 2017) | The evolution of teacher conceptions of STEM education throughout an intensive professional development experience | 2017 | Journal of Science Teacher Education | 110 |
| Shernoff et al. (Shernoff et al., 2017) | Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education | 2017 | International Journal of STEM Education | 244 |
| Guzey et al. (Guzey et al., 2016) | Building up stem: An analysis of teacher-developed engineering design-based stem integration curricular materials | 2016 | Journal of Pre-College Engineering Education Research | 111 |
| Canagarajah S. (Canagarajah, 2018) | Materializing 'Competence': Perspectives From International STEM Scholars | 2018 | Modern Language Journal | 158 |
| Dare et al. (Dare et al., 2018) | Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study | 2018 | International Journal of STEM Education | 92 |

Among these, Shernoff et al. (2017)study on teacher education and professional development needs, published in the *International Journal of STEM Education*, leads with 244 citations, underscoring the importance of teacher training for successful STEM integration. Similarly, Chalmers' (2018) research on robotics and computational thinking in primary schools (166 citations) and Corlu et al.'s (2014) introduction to STEM education for teachers (156 citations) emphasize innovative instructional methods and the evolving role of educators in STEM contexts. Other impactful works, such as Kelley et al.'s (2020) study on enhancing high school teachers' self-efficacy (117 citations) and Guzey et al.'s (2016) analysis of teacher-developed STEM curricular materials (112 and 111 citations across two publications), reveal a strong focus on teacher empowerment and curriculum design. Furthermore, Thibaut et al. (2018) and Ring et al. (2017) explore the influence of school environments and professional development experiences on STEM teaching practices, with 104 and 110 citations, respectively. These studies collectively reflect the academic community's interest in understanding and improving the intersection of teaching methodologies, teacher readiness, and curricular innovation in STEM education. Their high citation counts signify their broad influence and relevance in addressing foundational and practical challenges in integrated STEM teaching.

### 5.4 RQ4: What are the popular keywords related to the study?

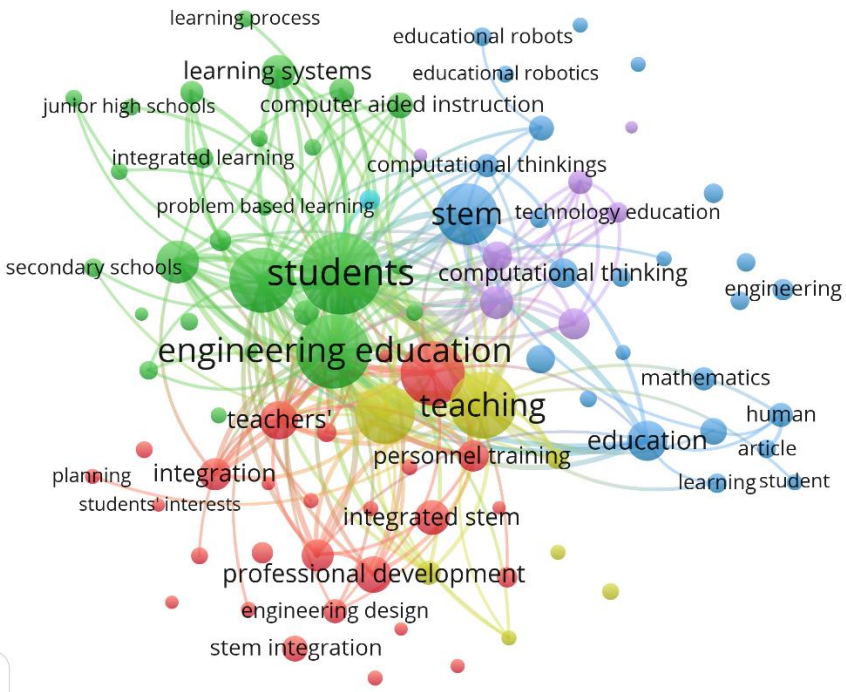


**Figure 3: Network visualization map of keywords' co-occurrence for integrated STEM teaching.**

The VOS-viewer analysis reveals that the most frequently occurring keywords related to integrated STEM teaching are "students" (343 occurrences) and "teaching" (231 occurrences), both with high link strengths (1931 and 1451, respectively). This indicates a strong focus on the roles of students and teaching approaches within STEM education research. The prominence of "students" highlights the importance of student-centred approaches and outcomes in STEM fields. Meanwhile, the significant link strength of "teaching" suggests extensive exploration of instructional methodologies and their impact, reflecting the central role of pedagogy in STEM integration studies.

Further analysis demonstrates a substantial emphasis on STEM-specific terms like "STEM (science, technology, engineering, and mathematics)" with 218 occurrences and a link strength of 1277, and "STEM education" with 212 occurrences and a link strength of 636. These high values underscore the broad interest in defining and assessing STEM education. Other related terms such as "curricula" (184 occurrences, 1200 link strength) and "education" (85 occurrences, 461 link strength) reflect a focus on curriculum development and educational frameworks necessary for effective STEM teaching. These keywords highlight an ongoing interest in teaching strategies and curriculum structures that facilitate STEM learning.

The keywords "computational thinking" (45 occurrences, 168 link strength), "professional development" (71 occurrences, 290 link strength), and "project-based learning" (33 occurrences, 208 link strength) indicate key areas of practical application and teacher preparedness in STEM. This suggests that computational thinking and project-based learning are frequently integrated into STEM teaching to encourage problem-solving and critical thinking skills among students. The high occurrences of "professional development" imply a strong recognition of the need to equip educators with the skills and knowledge to deliver integrated STEM education effectively. These findings collectively illustrate the field's

emphasis on innovative teaching methods, teacher training, and student-centred learning in enhancing STEM education.

### 5.5 RQ5: What are co-authorship countries' collaboration?

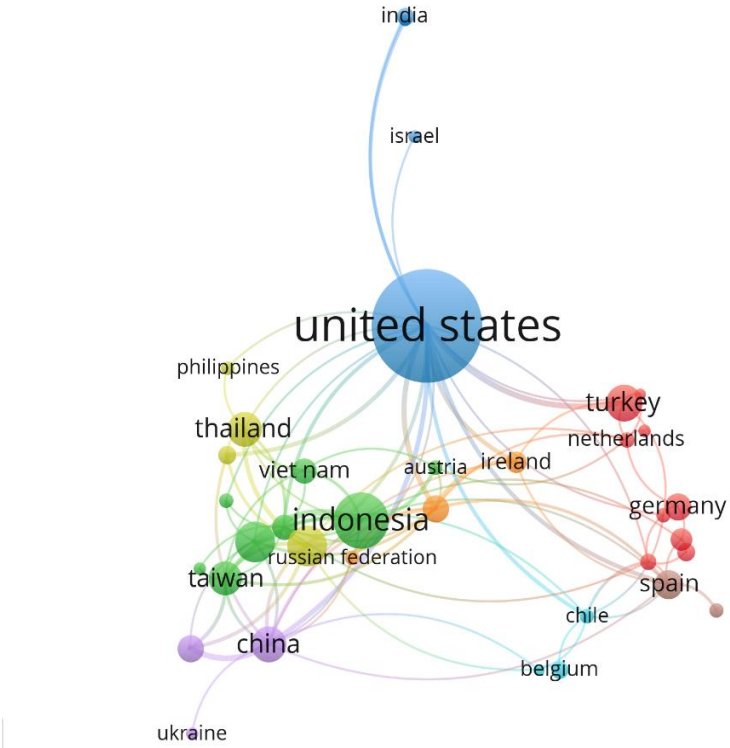


**Figure 4: The countries whose authors collaborate on STEM-integrated teaching.**

The co-authorship analysis of countries in integrated STEM teaching research reveals significant global collaboration patterns, with the United States (453 documents, 4849 citations, link strength 53) leading both in productivity and influence. Its high citation count and link strength suggest it is a major collaborator and influencer, likely due to its established research infrastructure and active role in STEM education advancements. Consequently, countries like China (47 documents, 381 citations, link strength 29) and Australia (61 documents, 1001 citations, link strength 24) also show strong contributions, underscoring their active engagement in STEM research and collaboration networks. China's high link strength reflects its strategic partnerships in STEM education research, likely due to its growing emphasis on STEM fields to bolster technological and educational advancement.

Other countries with significant collaboration and moderate productivity include Indonesia (112 documents, 403 citations, link strength 26) and the United Kingdom (27 documents, 356 citations, link strength 22). Indonesia's high document count but relatively moderate citation count suggests a burgeoning interest in STEM education, with the potential for a more significant impact as the research field matures. Similarly, the United Kingdom's substantial citation count and link strength indicate robust research outputs and influential collaborations, possibly reflecting the country's emphasis on STEM in policy and education reform. Malaysia (59 documents, 458 citations, link strength 19) and Taiwan (42 documents, 494 citations, link strength 18) also stand out, showing high research activity and collaboration strength, which suggests active regional participation in integrated STEM education research.

Smaller countries in terms of document output, such as Hong Kong (27 documents, 412 citations, link strength 14) and Thailand (43 documents, 231 citations, link strength 12), also show relatively high citation counts, indicating that their research contributions are well-regarded and impactful. This pattern and countries like Ireland and Singapore suggest that even with fewer resources or smaller academic communities, these countries contribute valuable insights and findings to the global discourse on STEM education. Overall, the data shows a diverse global network where major players like the United States, China, and Australia lead in collaboration, while smaller or emerging countries are steadily increasing their contributions to the integrated STEM teaching research landscape.

## 6. Discussion

The analysis of integrated STEM teaching publications highlights a rapidly expanding research field, particularly from 2018 onwards. From 2015 to 2018, research in this area was limited in the early years, signifying an emerging interest that had yet to gain momentum. However, as educational institutions began to widely adopt and support STEM initiatives, interest and funding in STEM research increased. By 2022, the field had solidified, with over 150 studies published annually. This surge in publications reflects integrated STEM teaching's growing significance. However, a slight plateau in growth observed in 2024 suggests a potential shift towards more specialized areas within STEM education as foundational research matures.

A small group of influential authors has been instrumental in shaping the field's direction. Key figures, such as T.S. Love and T.J. Moore, contributed substantially by establishing theoretical frameworks and pioneering methodological approaches. Following their lead, other researchers, including G.H. Roehrig and Abdurrahman, have further enriched the discourse, focusing on curriculum design and instructional methodologies. This blend of foundational and expanding contributions demonstrates a collaborative research environment where seasoned experts and emerging scholars work together to advance STEM education through integrated teaching practices.

Citation analysis underscores the impact of specific researchers whose work resonates widely in integrated STEM education. Shernoff D.J., for instance, stands out with a high citation count for research emphasizing innovative instructional strategies. Additionally, the work of Chalmers C. and Kelley T.R., both highly cited, reflects an emphasis on computational thinking and teacher efficacy. These influential publications cover a spectrum from theoretical models to practical applications, showcasing a balanced approach in integrated STEM research that addresses policy-level concerns as well as specific classroom practices, contributing to a holistic understanding of STEM education.

Internationally, the United States leads in publication output and influence, reflecting its extensive role in advancing integrated STEM education. Other significant contributors, including China, Australia, and the United Kingdom, exhibit strong collaboration networks and research output. Notably, emerging contributors like Malaysia, Taiwan, and Hong Kong add valuable perspectives, highlighting the diversity within the STEM research community. This global collaboration reflects a shared commitment to developing effective STEM education practices, with countries of various academic strengths contributing collectively to the research landscape. The international nature of this research emphasizes the universal importance of integrated STEM education and the dedication to continuous improvement through diverse, cooperative research efforts.

## 7. Conclusion

The bibliometric examination of integrated STEM education approaches underscores a swiftly advancing domain propelled by heightened attention, financing, and governmental endorsement in recent years. This study, bolstered by substantial contributions from prominent scholars and increasing international collaboration, elucidates critical themes like instructional methods, teacher preparation, curriculum creation, and the incorporation of novel technology. Despite the maturation and diversification of the research sector, it is essential to address difficulties such as interdisciplinary integration and teacher preparedness. The insights obtained establish a basis for additional investigation, especially in nascent fields that integrate STEM education with the changing requirements of global education and the workforce.

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