International Journal of Learning, Teaching and Educational Research
Vol. 24, No. 9, pp. 940-965, September 2025
https://doi.org/10.26803/ijlter.24.9.45
Received Jul 5, 2025; Revised Aug 6, 2025; Accepted Aug 20, 2025

Mapping the Evolution of STEAM Education: A Bibliometric Analysis of Global Trends from 2016 to 2025

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Abstract. This study presents a comprehensive bibliometric analysis of Science, Technology, Engineering, Arts, and Mathematics (STEAM) education research from 2016 to 2025, to map publication trends, identify influential sources, authors, and countries, and reveal the intellectual structure and thematic evolution within the field. Data were systematically extracted from the SCOPUS database, resulting in a final sample of 1,097 peer-reviewed journal articles. The analysis employed advanced bibliometric mapping tools, including VOSviewer and Biblioshiny, to examine annual publication output, citation impact, author networks, journal productivity, and keyword co-occurrence. The results indicate a substantial increase in scholarly output, particularly between 2019 and 2024, with a slight decline in 2025, suggesting possible thematic consolidation. The field is characterized by a strong presence of interdisciplinary and international collaborations, with leading contributions from authors and institutions in the United States, China, and Spain. Core research themes have evolved from foundational curriculum integration to encompass creativity, computational thinking, sustainability, and equity. Thematic analysis highlights the emergence of new areas such as digital transformation, environmental education, and maker education. While this study offers a comprehensive synthesis, it is limited to SCOPUS-indexed publications. Future research could expand this scope by incorporating data from other databases or exploring longitudinal citation dynamics across regional clusters.

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Keywords: Educational innovation; STEAM education; science mapping; publication trends; STEM to STEAM

1. Introduction

Integrating Science, Technology, Engineering, Arts, and Mathematics (STEAM) education has become a prominent interdisciplinary approach to enhance educational outcomes and equip learners with essential 21st-century skills (Ng et al., 2022; Suganda et al., 2021). This model emphasizes the fusion of technical proficiency with creativity, preparing students for complex, innovative-driven environments (Li et al., 2022; Sit, 2022). It encourages the development of critical thinking, collaboration, and problem-solving skills through experiential learning methods (Bertrand & Namukasa, 2020). The inclusion of arts fosters a holistic understanding by bridging conceptual and practical domains, empowering students to connect disciplines in meaningful ways (Munawar et al., 2024). STEAM's interdisciplinary nature positions it as a response to real-world challenges that transcend the boundaries of singular academic subjects (Razi & Zhou, 2022).

Despite increasing interest, STEAM education remains underexplored through large-scale, systematic analyses. Numerous studies confirm its benefits for student motivation, creativity, and academic achievement (Hsiao & Su, 2021; Li, 2023; Santi et al., 2021). Countries across the globe have begun incorporating STEAM frameworks into national curricula to align educational goals with workforce demands and global citizenship priorities (Chandir & Görur, 2021; Chen & Ding, 2023). The conceptual focus on learner agency and adaptability reflects broader shifts in educational paradigms and policymaking (Ma et al., 2022; Cocha & Chocholakova, 2023). However, the growing corpus of research lacks consolidation, and limited bibliometric overviews leave gaps in understanding the evolution of key themes, major contributors, and research directions from 2016 to 2025 (Habibi, 2023; Lam et al., 2023).

The present study addresses this gap by conducting a comprehensive bibliometric mapping of STEAM education research published between 2016 and 2025. By utilizing SCOPUS-indexed journal articles as a data source, this study systematically examines publication trends, key authors, influential journals, and thematic developments (Marín et al., 2021; Deák & Kumar, 2024; Prahani et al., 2023). Bibliometric methods such as co-authorship, keyword co-occurrence, and citation analysis offer a macro-level view of the research landscape, providing quantitative insights that support qualitative interpretation (Li & Wong, 2023). Identifying emerging themes, collaborative networks, and geographic trends enables a better understanding of how STEAM education is evolving in practice and scholarship. In doing so, the study contributes to the design of targeted educational strategies and the development of integrative curricula.

This research also situates itself within the broader literature on bibliometric methodologies in educational fields. Studies by Aria et al. (2024), Visser et al. (2021), and Sandu et al. (2023) have demonstrated the effectiveness of tools such as VOSviewer and Biblioshiny in visualizing scientific collaboration and thematic evolution. These tools support transparent, reproducible analysis and are increasingly used to assess interdisciplinary fields such as STEAM (Caputo & Kargina, 2021). They reveal intellectual structures, co-authorship networks, and topic diffusion patterns that inform research policy and funding priorities. Additionally, prior research has underscored the importance of combining qualitative synthesis with bibliometric mapping to create a fuller picture of field development (Dienana et al., 2024; Conradty & Bogner, 2019). This dual approach helps distinguish between influential conceptual contributions and peripheral trends.

The literature on STEM and STEAM transitions highlights a paradigm shift from content-driven instruction to design-oriented, learner-centered approaches. Researchers have increasingly emphasized creativity and innovation as educational priorities, reflected in policy reforms and pedagogical frameworks (Dienana et al., 2024; Deng et al., 2024). The integration of arts into STEM subjects is seen not merely as aesthetic enhancement, but as a catalyst for deeper learning and engagement (Sandu et al., 2023). These trends affirm the need to understand how STEAM education adapts to societal needs and technological transformation. However, most existing studies focus on specific regions or institutional initiatives, offering limited generalizability. A broader bibliometric analysis can clarify the global scope and direction of STEAM research.

Building on this foundation, the study aimed to answer the following research questions:
1. What are the publication trends and growth patterns in STEAM education research between 2016 and 2025?
2. Who are the most influential authors, institutions, and countries in this field?
3. Which journals serve as the primary outlets for STEAM-related publications?
4. What are the dominant and emerging research themes in STEAM education?
5. How have collaboration networks and thematic emphases evolved over the past decade?

By addressing these questions, the study contributes an empirical foundation for advancing STEAM education through policy, curriculum design, and international research collaboration. The results will inform stakeholders about the intellectual evolution of the field and provide guidelines for future research development.

2. Method

This study employed a comprehensive bibliometric mapping methodology to analyze research trends in STEAM education over the period from 2016 to 2025. The primary source of data for this bibliometric study was the SCOPUS database, recognized as one of the largest and most authoritative abstract and citation databases of peer-reviewed literature. Data was extracted directly from the SCOPUS interface in CSV and RIS formats. Fields included title, authors, abstract, keywords, affiliations, citations, and publication source. To ensure methodological robustness, the extraction protocol underwent expert review prior to analysis, ensuring alignment with bibliometric standards and minimizing data omission or redundancy. SCOPUS was selected due to its wide coverage of international journals, rigorous indexing standards, and its established use in bibliometric and scientometric studies, thus ensuring data comprehensiveness and reliability (Visser et al., 2021).

A systematic and reproducible electronic data retrieval was conducted on June 19, 2025. The search strategy utilized a targeted approach, employing the keyword combination "Steam AND Education" applied to the fields of title, abstract, and keywords (TITLE-ABS-KEY). The search employed the Boolean string:
TITLE-ABS-KEY ("STEAM" AND "Education") AND ("learning" OR "teaching" OR "curriculum" OR "assessment")

2.1 Sample Preparation

To ensure analytical rigor and relevance, a multi-stage filtering process was implemented using predefined inclusion and exclusion criteria, as detailed in Table 1. These criteria were designed to align with best practices in bibliometric research and enhance reproducibility.

Table 1: Inclusion and exclusion criteria

Criteria Category	Inclusion Criteria	Exclusion Criteria
Publication Type	Peer-reviewed journal articles	Conference papers, reviews, book chapters, editorials
Language	English	Non-English publications
Publication Year	2016–2025	Outside the 2016–2025 range
Educational Level	Studies involving high school, undergraduate, or higher education settings	Studies focusing exclusively on early childhood or non-formal education
Methodology	Qualitative, quantitative, mixed-methods, and case study research designs	Theoretical or conceptual-only papers without empirical data

This formulation ensured a comprehensive capture of relevant literature. The terms were refined iteratively and validated by three independent experts in science education and bibliometric methods to verify coverage breadth and thematic relevance. Regarding the exclusion of 1,546 records, these include 358 records filtered by year (pre-2016 or post-2025), 1,000 records excluded as non-peer-reviewed types (conference papers, reviews, books), and 188 records removed based on language or irrelevant educational level or methodology. This exclusion breakdown is clearly aligned with the narrative in Section 2.1 and Figure 1.

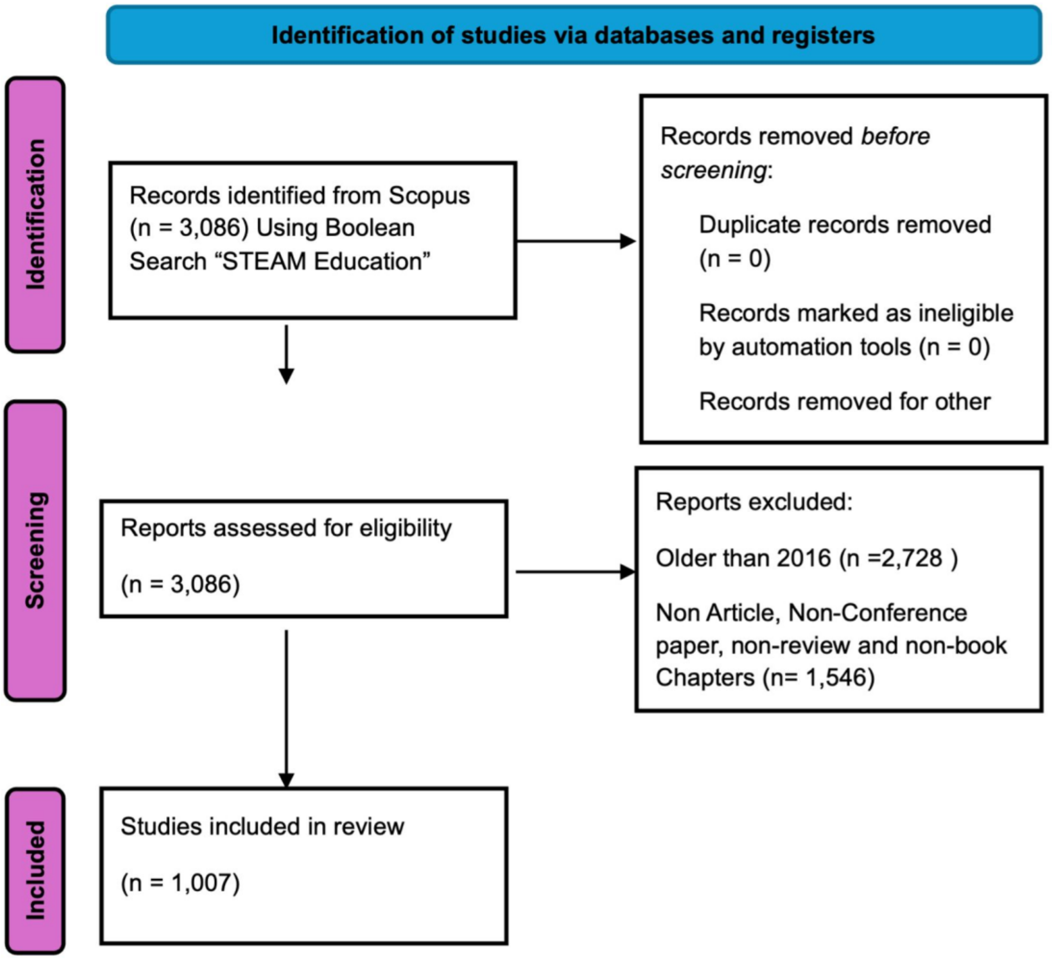

Figure 1: The PRISMA flow diagram detailing the screening and selection process of literature

2.2 Experimental Set-Up

The analytical workflow was structured to maximize the extraction of meaningful patterns from the bibliometric data and to enhance the reproducibility of the study (Aria et al., 2024; Aria & Cuccurullo, 2017)The primary analytical tools utilized were Microsoft Excel, VOSviewer, and Biblioshiny (the web interface for the R package bibliometrix). Microsoft Excel was employed for the initial organization, cleaning, and basic statistical analysis of the raw data, including frequency counts, annual publication trends, and descriptive statistics. VOSviewer (van Eck & Waltman, 2017) was used for constructing and visualizing bibliometric networks, such as co-authorship, keyword co-occurrence, and bibliographic coupling networks, owing to its ability to handle large datasets and to provide high-resolution network mapping. Biblioshiny, built on the bibliometrix R-package, facilitated advanced bibliometric analysis, including thematic mapping, trend topics, and collaboration patterns (Aria et al., 2024).

The methodological sequence included data importation, data cleaning (e.g., duplication, normalization of author and affiliation names), and the application of descriptive and network-based bibliometric analyses. Bibliometric indicators such as the number of publications, citations, authorship, source title productivity, international collaboration rates, and keyword evolution were systematically extracted. Network visualizations were generated to elucidate collaboration structures, emerging themes, and the intellectual structure of the field. Each stage of analysis was carefully documented to ensure full methodological transparency.

2.3 Parameters

Several bibliometric parameters and indicators were measured to characterize the research landscape of STEAM education. The core parameters included:

- **Publication Output**: Annual and cumulative number of articles published, revealing growth trends and shifts in scholarly attention.
- **Source Analysis**: Distribution of articles by source title, identification of leading journals, and cumulative occurrences over time.
- **Authorship and Collaboration**: Analysis of author productivity, international collaboration (single-country vs. multiple-country publications), author affiliations, and geographical distribution of contributions.
- **Citation Analysis**: Identification of highly cited articles, influential authors, and countries, enabling the assessment of research impact and visibility.
- **Keyword Analysis**: Extraction and co-occurrence mapping of author keywords to identify core research topics, thematic clusters, and evolving trends in literature.
- **Thematic and Trend Analysis**: Thematic mapping, trend topic visualization, and evolution analysis to reveal the intellectual structure and development of the STEAM education field.

Each parameter was systematically derived from the filtered SCOPUS dataset using the analytical tools described, and was visualized through charts, maps, and network diagrams for interpretive clarity.

2.4 Statistical Analysis

Quantitative and network-based bibliometric analyses were conducted to ensure robust and reproducible results (Phương et al., 2023; Prahani et al., 2023). Descriptive statistics (e.g., frequencies, percentages, annual growth rates) were generated using Microsoft Excel. Advanced statistical mapping and network analyses, including co-occurrence, co-authorship, and bibliographic coupling, were performed with VOSviewer (Furstenau et al., 2021).

The bibliometrix R-package was employed for conceptual structure analysis, thematic evolution, and trend topic mapping, utilizing methodologies validated in prior comparative science mapping studies (Prahani et al., 2023). All visualizations were systematically reviewed for interpretive coherence (Aktaş, 2022). Where appropriate, normalization techniques (e.g., fractional counting) were applied to adjust for multiple authorship or affiliations. Data integrity was maintained throughout, and each step of the analysis was cross-validated for accuracy.

The combination of descriptive and advanced network-based bibliometric analysis enabled a comprehensive mapping of the STEAM education research landscape (Joseph et al., 2024). The use of multiple validated software tools and adherence to established protocols ensured the rigor, transparency, and replicability of the methodological approach, consistent with recent methodological advancements in bibliometric science mapping (Joseph, Jose, Ettaniyil, et al., 2024; Phuong et al., 2023).

3. Results

3.1 Yearly Trend of Publications and Citations

Figure 2 demonstrates the annual trend in scientific production for STEAM education articles from 2016 to 2025, as extracted from the SCOPUS database. A total of 1,007 documents were analyzed, focusing exclusively on journal articles. The data indicates a fluctuating but generally increasing trend in publication output. In 2016, 33 articles were published, followed by a slight decrease to 26 articles in 2017. From 2018 onwards, there has been a consistent increase, with 42 articles in 2018, 59 in 2019, and a marked surge to 92 articles in 2020. This upward momentum continues through 2021 (120 articles), 2022 (147 articles), and 2023 (162 articles), peaking in 2024 at 197 articles. The year 2025 shows a decline to 129 articles, which may reflect either a correction after the preceding peak or shifts in research priorities.

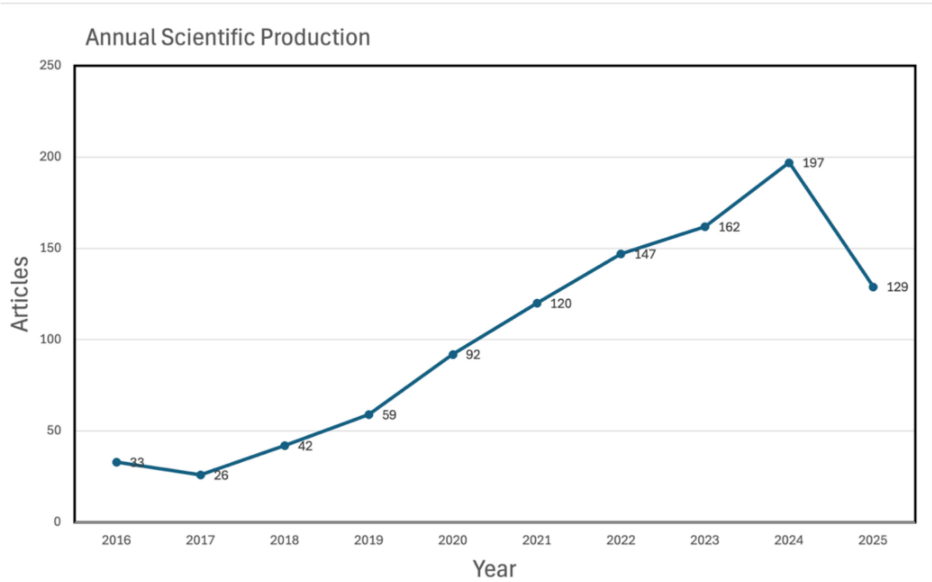

Figure 2: Number of articles published each year from 2016–2025

This pattern signifies an escalating interest in STEAM education research over the past decade, particularly evident in the period between 2019 and 2024. The pronounced increase in publications aligns with a global shift towards interdisciplinary and integrative educational approaches that address the complexities of modern teaching and learning environments. The observed decline in 2025 warrants further attention, as it could signal a maturation phase or evolving trends in academic focus within the field.

Table 2: Highly cited STEAM education research

Rank	Title	Year	Source title	Cited by	Authors
1	Exploring Teachers' Perceptions of STEAM Teaching Through Professional Development: Implications for Teacher Educators	2017	Professional Development in Education	159	Herro D., & Quigley C.
2	"Finding The Joy in The Unknown": Implementation of STEAM Teaching Practices in Middle School Science and Math Classrooms	2016	Journal Of Science Education and Technology	141	Quigley, C. F., & Herro, D.
3	How Creativity, Autonomy and Visual Reasoning Contribute to Cognitive Learning in A STEAM Hands-On Inquiry-Based Math Module	2018	Thinking Skills and Creativity	93	Thuneberg, H. M., Salmi, H. S., & Bogner, F. X.
4	Co-Measure: Developing an Assessment for Student Collaboration in STEAM Activities	2017	International Journal of STEM Education	84	Herro, D., & Quigley, C.
5	The Challenges of STEAM Instruction: Lessons from The Field	2019	Action In Teacher Education	72	Herro, D., & Quigley, C.
6	From Stem to STEAM: Cracking the Code? How Creativity & Motivation Interacts with Inquiry-Based Learning	2019	Creativity Research Journal	72	Bogner, F. X.
7	From Stem to STEAM: How to Monitor Creativity	2018	Creativity Research Journal	68	Bogner, F. X.
8	STEAM Teaching Professional Development Works: Effects on Students' Creativity and Motivation	2020	Smart Learning Environments	65	Bogner, F. X.
9	How Creativity in STEAM Modules Intervenes with Self-Efficacy and Motivation Study on the Application of Cultural Arts Education Service for Corporates - Corporate Case Studies	2020	Education Sciences Information (Japan)	61	Bogner, F. X.
10	A Theoretical Framework for Developing an Intercultural STEAM Program for Australian and Korean Students to Enhance Science Teaching and Learning	2019	International Journal of Science and Mathematics Education	48	Chu, He
11	Development And Validation of Evaluation Indicators for Teaching Competency in STEAM Education in Korea	2016	Eurasia Journal of Mathematics, Science and	46	Kim, J.

			Technology Education		
12	STEAM Designed and Enacted: Understanding the Process of Design and Implementation of STEAM Curriculum in An Elementary School	2020	Journal Of Science Education and Technology	44	Herro, D.
13	Prompt Aloud! Incorporating Image-Generative Ai into STEAM Class with Learning Analytics Using Prompt Data	2024	Education And Information Technologie s	37	Kim, J.
14	Connected Learning in STEAM Classrooms: Opportunities for Engaging Youth in Science and Math Classrooms	2020	Internationa l Journal of Science and Mathematics Education	35	Herro, D.
15	Developing and Evaluating Educational Innovations for STEAM Education in Rapidly Changing Digital Technology Environments	2022	Sustainabilit y (Switzerland)	34	Lavicza, Z., & Fenyvesi, K.

Table 1 highlights the most highly cited articles in STEAM education during the analysis period. The most cited article is "Exploring Teachers' Perceptions Of STEAM Teaching Through Professional Development: Implications for Teacher Educators" by (Herro & Quigley, 2017), with 159 citations, emphasizing the importance of professional development in advancing STEAM pedagogy. Other prominent works address topics such as the implementation of STEAM in middle school settings (Quigley & Herro, 2016), the role of creativity and autonomy in learning (Thuneberg et al., 2018), and assessment strategies for collaboration in STEAM activities(Herro et al., 2017) (Herro & Quigley, 2017).

The recurrent appearance of authors such as Herro, Quigley, and Bogner across multiple highly cited papers reflects their substantial contributions to the development and dissemination of STEAM education research. Furthermore, the inclusion of recent work addressing digital technologies and artificial intelligence (AI) (Lee et al., 2024) indicates the field's responsiveness to technological advancements and emerging educational needs. Collectively, the yearly trends and citation patterns reveal the growing scholarly impact and diversification of STEAM education research, underlining its importance as a multidisciplinary focus within contemporary education studies.

3.2 Most Relevant Sources

Figure 3 depicts the cumulative production of the most relevant source titles in STEAM education over time. The figure demonstrates distinct publication trajectories among leading journals in the field from 2016 to 2025. Among these, *Education Sciences* stands out with a consistently steep upward trend, especially since 2021, and reaches the highest cumulative occurrences by 2025. This trajectory indicates its significant and expanding role in disseminating STEAM education research. Other notable sources, such as *Eurasia Journal of Mathematics, Science and Technology Education*, *Frontiers in Education*, *Sustainability (Switzerland)*, and *Frontiers in Psychology*, also show marked increases, albeit with varied slopes and eventual plateaus.

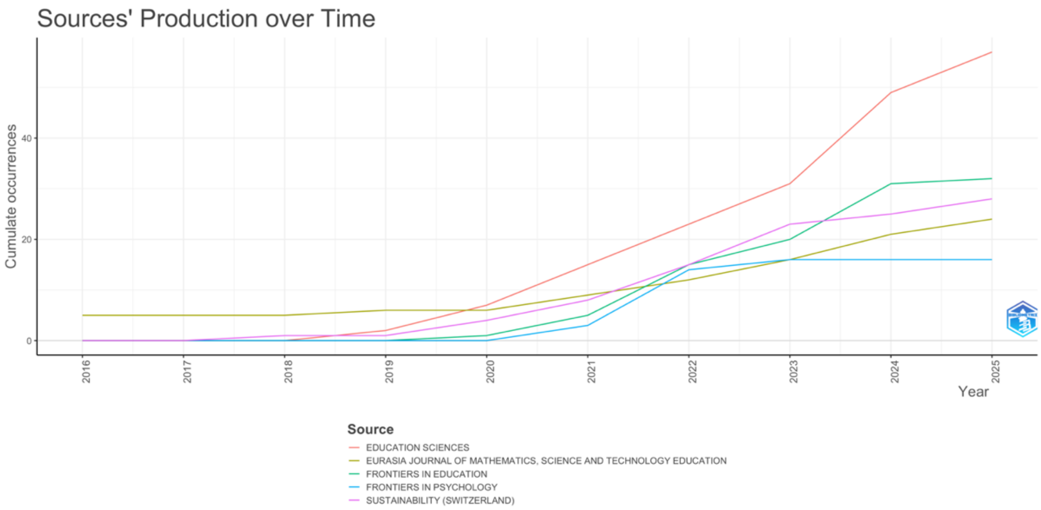

Figure 3: Sources' production over time

Table 2 further details the ten most relevant sources based on the number of published documents, citations, and total link strength in the STEAM education domain. *Education Sciences* leads with 60 documents, 531 citations, and a total link strength of 51, confirming its dominant influence. *Frontiers in Education* (32 documents, 197 citations), *Sustainability (Switzerland)* (30 documents, 504 citations), and *Eurasia Journal of Mathematics, Science and Technology Education* (24 documents, 473 citations) also rank highly, each contributing substantial scholarly output and serving as major publication venues for STEAM-related research. Notably, *Thinking Skills and Creativity*, despite having only 13 documents, matches the top citation count (531) and holds the highest total link strength (84), indicating significant impact per publication.

These findings suggest that the dissemination of STEAM education scholarship is concentrated in several interdisciplinary and internationally recognized journals. The increasing cumulative occurrences for key sources reflect a growing academic and professional audience. Furthermore, the distribution of citations and link strengths highlights both productivity and influence, with certain journals serving as critical nodes in the intellectual network of STEAM education research. This pattern illustrates the interconnectedness and collaborative nature of the field, providing robust platforms for advancing research, policy, and practice in STEAM education.

Table 3: 10 most source titles that contribute to the publication on STEAM education

Rank	Relevant sources	Document	Citation	Total link strength
1	Education Science	60	531	51
2	Frontiers in Education	32	197	24
3	Sustainability (Switzerland)	30	504	20
4	Eurasia Journal of Mathematics, Science and Technology Education	24	473	44
5	Frontiers in psychology	16	174	19
6	International Journal of Technology and Design Education	15	346	28
7	Thinking Skills and Creativity	13	531	84
8	Education and Information Technologies	9	155	6
9	Asia-Pacific Science Education	9	62	17
10	Journal of Baltic Science Education	9	40	14

3.3 Most Influential Authors

Figure 4 shows a three-field plot linking authors' countries (AU_CO), individual authors (AU), and their affiliated universities (AU_UN). Austria and China demonstrate the strongest collaborative networks. Austria is notably represented by Lavicza and Bogner from Johannes Kepler University, while China is linked to multiple prolific authors and key institutions such as Beijing Normal University and Central China Normal University. In contrast, Korea shows a more limited network, with authors such as Kim J. and Hong J-C. affiliated with Seoul National University and Korea National University of Education, respectively. Notable contributors also include Quigley C. from Clemson University (USA), reinforcing the USA's diverse institutional involvement. Overall, Figure 4 highlights Austria and China as central hubs in the research network, with the USA and Korea playing varying but important roles.

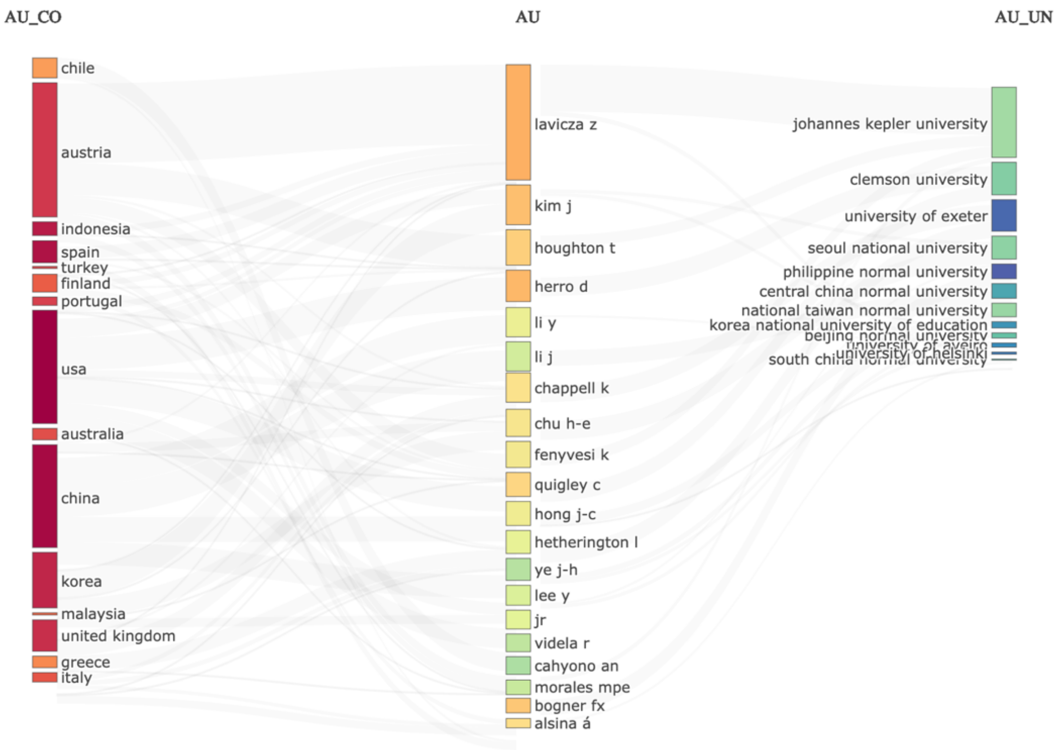

Figure 4: Three-field plot of authors, author country, and affiliation

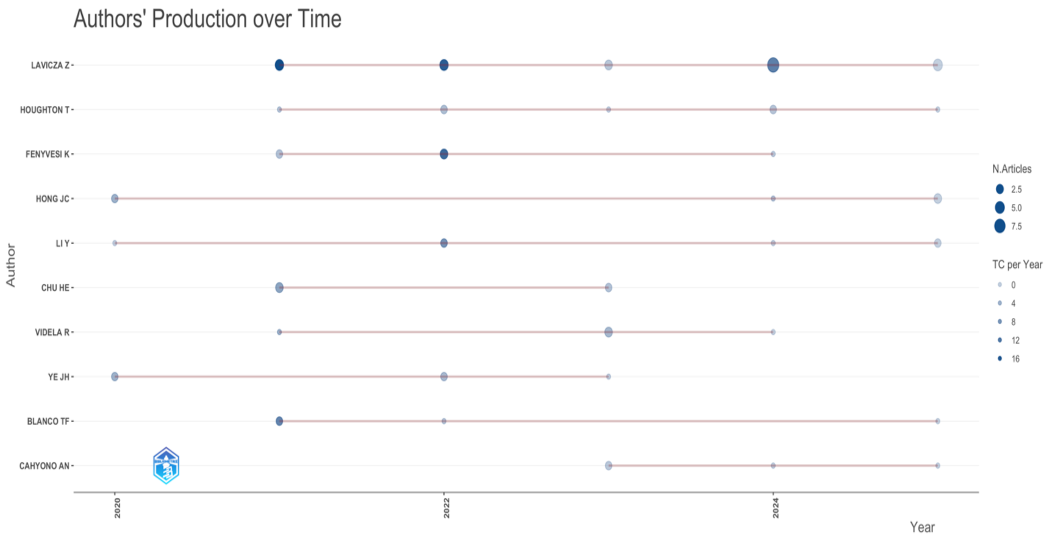

Figure 5: Authors' production over time

Figure 5 shows the productivity and impact of the top authors over time. Authors such as Lavicza, Herro, Kim and Bogner have demonstrated sustained scholarly output and influence, with their publications dispersed over several years. Lavicza and Herro stand out for their continuous and high volume of publications, particularly in recent years, reflecting their sustained leadership in the field. Bogner and Kim are also notable for their consistent publication activity and influence, as indicated by the larger bubble sizes, which correspond to a higher number of articles and citations per year. Other influential authors, such as Quigley, Houghton, and Fenyvesi, have contributed significantly at various intervals, underscoring the collaborative and evolving nature of research in STEAM education. In summary, the field of STEAM education is shaped by a core group of highly productive and influential authors, many of whom are affiliated with prominent institutions in North America, Europe, and Asia. Their sustained scholarly activity and extensive collaboration networks are central to advancing research, policy, and practice in STEAM education on a global scale.

3.4 Most Influential Country

Figure 6 presents the analysis of corresponding authors' countries in STEAM education research, distinguishing between single-country publications (SCP) and multiple-country publications (MCP).

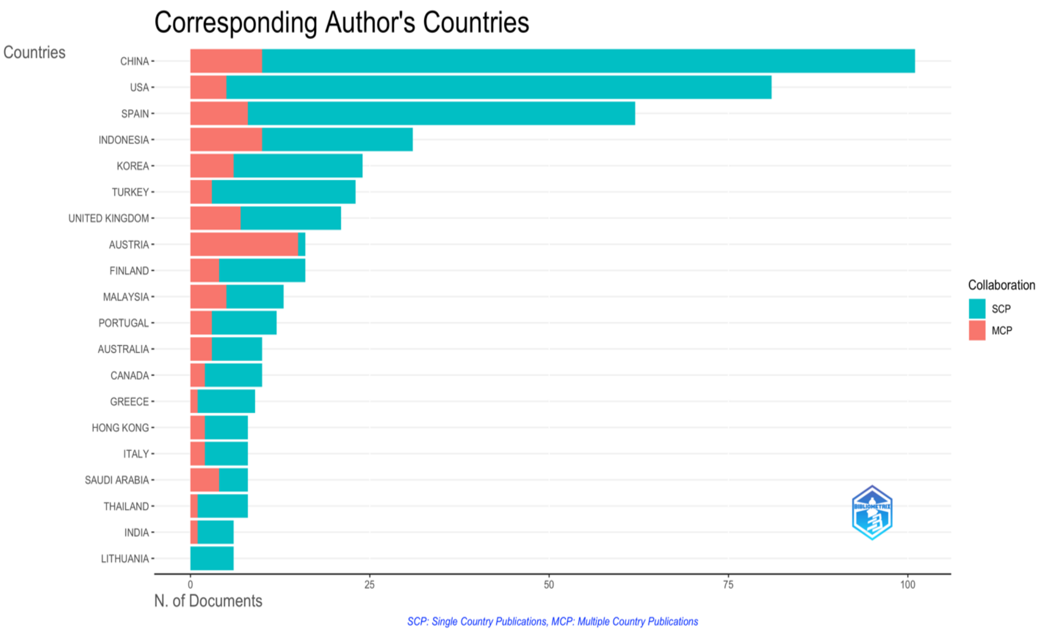

Figure 6: Corresponding author's countries: Geographical collaboration: single-country and multiple-country publications

Austria stands out as the most proportionally collaborative country (highest MCP compared to SCP), while China leads in total publications, with a predominance of domestic research (SCP). The United States demonstrates a balance between international collaboration and high domestic production, making it a key hub in the global STEAM research network.

Figure 7, illustrating the bibliographic coupling of countries, further underscores the dominance of the United States, China, and Spain as central nodes in the global STEAM education research network. The heatmap reveals that these countries are not only prolific in publication volume but are also highly interconnected with other countries through shared references and research agendas. The prominence of countries such as the United Kingdom, Germany, Australia, Malaysia, and Turkey reflects their pivotal roles in shaping and disseminating STEAM education knowledge. Notably, the map demonstrates extensive global participation, with significant research communities spanning North America, Europe, and Asia, as well as emerging networks in regions such as Latin America and Africa.

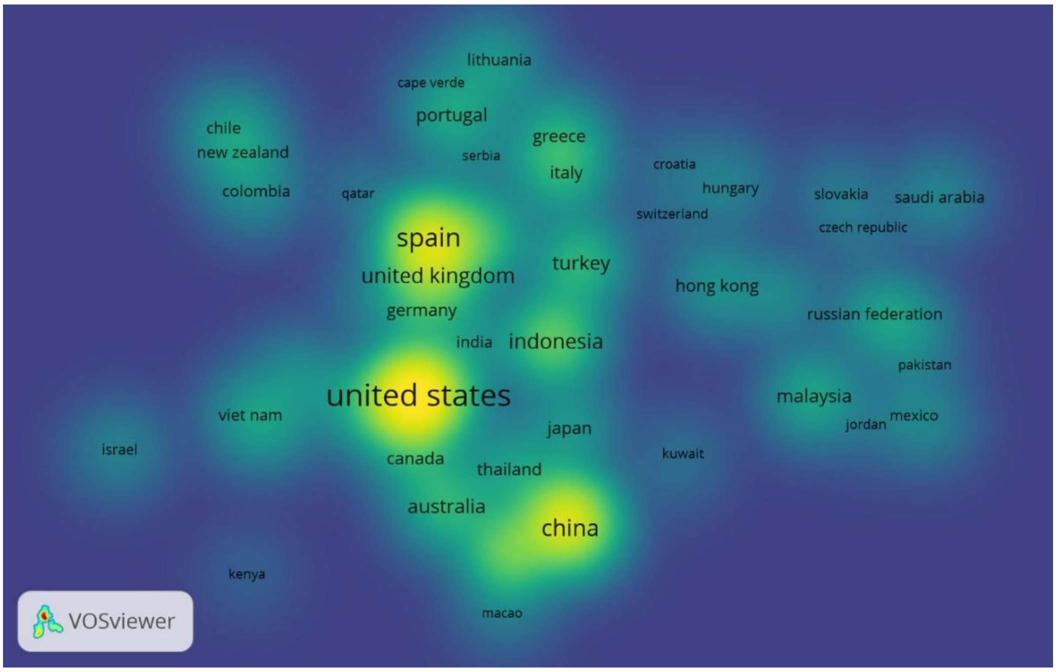

Figure 7: Bibliographic coupling of countries

The combined evidence from publication output and bibliographic coupling highlights the United States as the most influential country in STEAM education research, driving both innovation and collaboration at an international level. China and Spain, with their high publication volume and strong collaborative networks, also serve as major contributors to the global advancement of the field. This international dispersion of research activity signifies that STEAM education is a priority area for educational development worldwide, with diverse countries actively engaged in advancing interdisciplinary learning and pedagogical innovation.

3.5 Most Relevant Keywords

Figure 8 presents a tree map of authors' keywords used in STEAM education research from 2016 to 2025. The visualization shows that "STEAM" (243 occurrences) and "STEAM education" (177 occurrences) are the most dominant keywords, indicating the central focus of the field. Other frequently used terms include "students" (64), "engineering education" (56), "STEM" (54), and "education" (46), highlighting the emphasis on learners, interdisciplinary content, and educational practices.

Keywords such as "creativity", "technology", "science education", and "curriculum" suggest a strong pedagogical orientation. Emerging themes such as "computational thinking", "design thinking", "sustainability", and "robotics" reflect growing interest in digital skills, innovation, and real-world relevance.

The presence of niche keywords such as "augmented reality", "gender", and "maker education", although less frequent, points to diversification within the field. Overall, the tree map illustrates a broad and evolving research landscape, with a blend of foundational and innovative topics shaping the discourse on STEAM education.

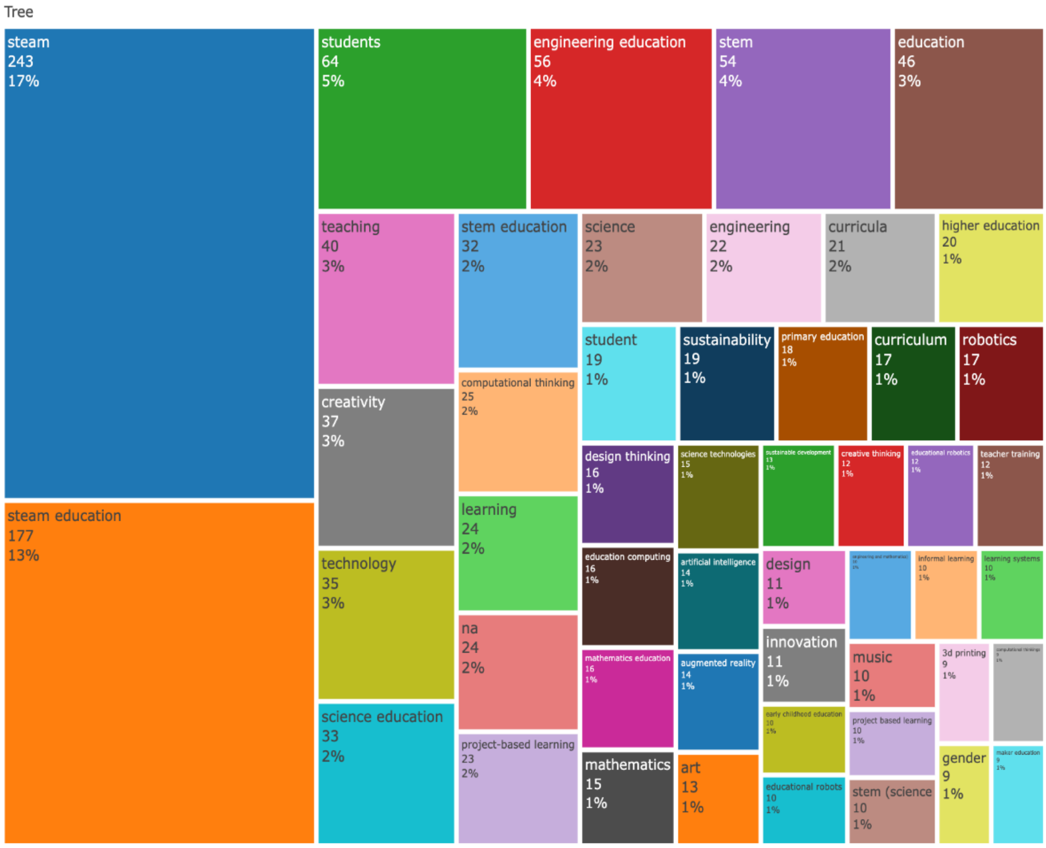

Figure 8: Tree map of authors' keywords

Figure 9 visualizes the co-occurrence network of keywords, highlighting the interconnectedness of principal research themes. Signifying their pivotal roles in the STEAM education research landscape, terms such as "STEAM," "students," "computational thinking," "learning," and "technology" emerge as central nodes. The network also features clusters around "early childhood education," "arts education," "education computing," "gender," and "active learning," demonstrating the field's multidimensionality. The color gradient indicates the temporal evolution of research focus, with certain topics such as "sustainability," "design thinking," and "integrated learning" becoming more prominent in recent years (2022–2023).

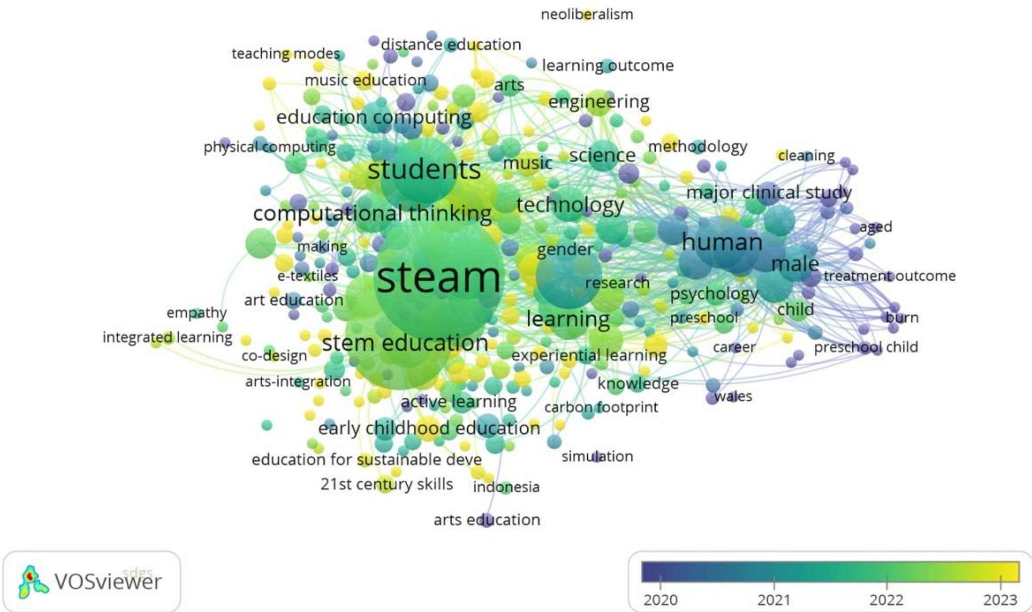

Figure 9: Keywords co-occurrence analysis by network visualization

Together, the tree map and network visualization confirm that STEAM education scholarship is characterized by a rich interplay of pedagogical innovation, interdisciplinary content, and a continuous emergence of new focal areas. The prominence of terms such as "students," "learning," and "creativity" highlights the learner-centered and integrative orientation of current research, while the expanding appearance of terms such as "computational thinking," "innovation," and "sustainability" points toward future directions and evolving priorities in the field.

3.6 The Current Research Landscape in STEAM Education

Figure 10 presents trend topics in STEAM education research over the period 2016 to 2025. The analysis reveals that terms such as "steam," "steam education," "stem education," "students," "education," and "teaching" have consistently remained central themes, each demonstrating sustained frequency and significance throughout the decade. In recent years, terms such as "critical thinking," "higher education," "early childhood education," and "professional development" have become increasingly prominent, reflecting the diversification of research foci and the evolving challenges addressed by the field.

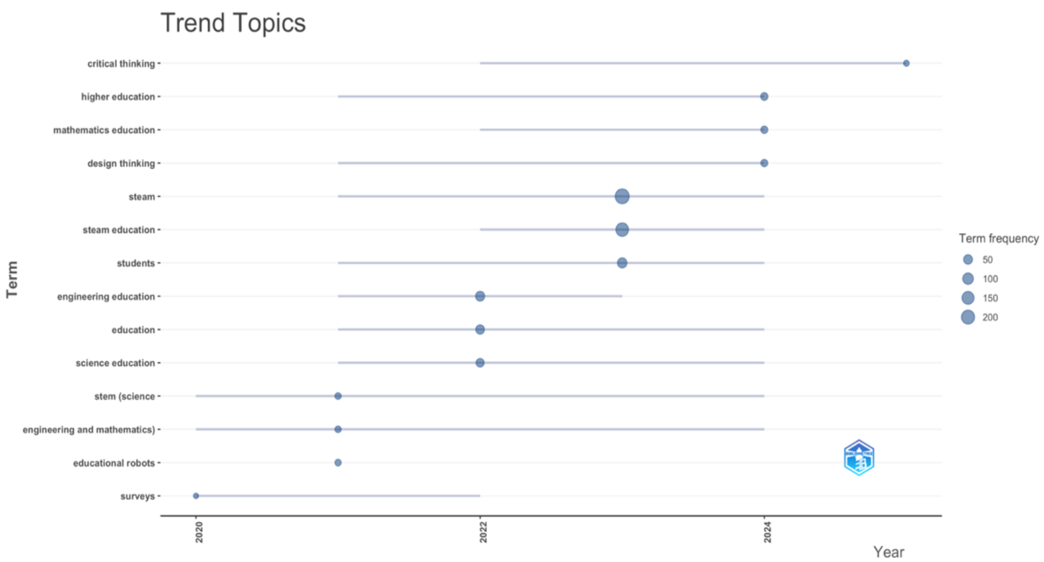

Figure 10: Trend topics of STEAM education

Figure 11 offers a thematic map that categorizes the research themes based on their relevance (centrality) and level of development (density). "STEAM," "STEM," and "education" are positioned as motor themes—both highly developed and central to the field—signifying their status as driving forces in research. Related motor themes include "students," "engineering education," and "computational thinking," underscoring the importance of learner-centered, interdisciplinary, and technology-enhanced pedagogies.

In contrast, themes such as "collaborative learning" and "digital technologies" are situated as niche or emerging themes, indicating areas of growing but, as yet, less central focus. The basic themes cluster, including "creativity," "science education," and "steam education," highlights essential and foundational concepts that are widely referenced but potentially less densely developed in the current literature.

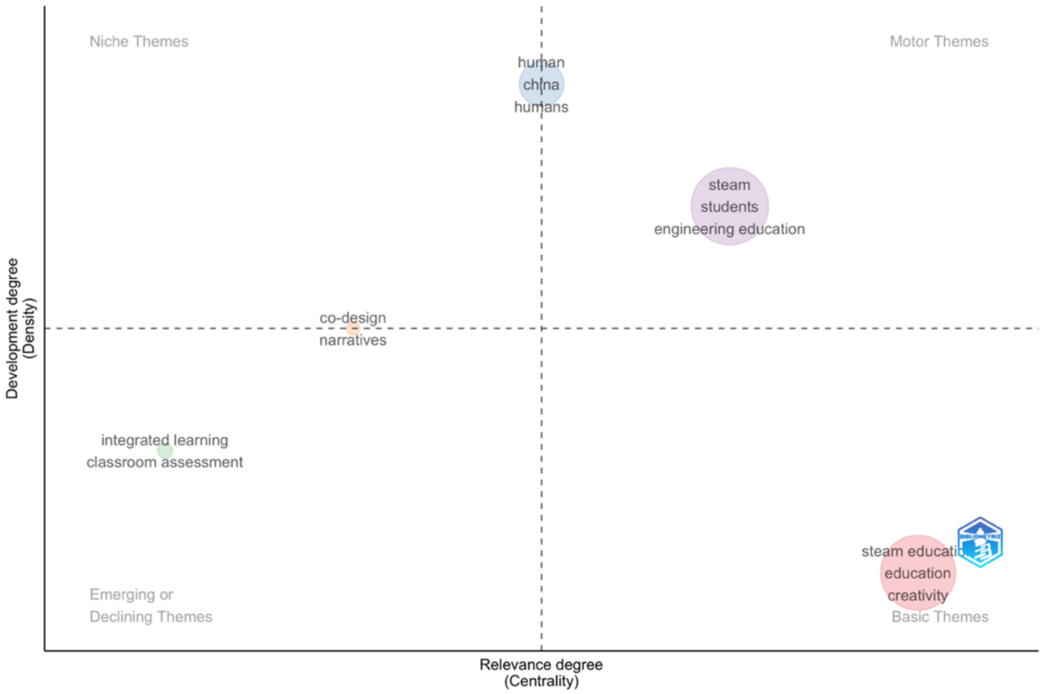

Figure 11: Thematic map of STEAM education

Figure 12 depicts the thematic evolution of STEAM education from 2016 to 2025. The visualization demonstrates the dynamic nature of the field, with early research (2016–2020) centered on foundational concepts such as "steam," "education," "curriculum," and "early childhood education." In the period 2021–2023, there was a noticeable shift towards emerging themes such as "game-based learning," "pedagogy," "co-creation," and "collaboration." By 2024–2025, the field further diversified, emphasizing advanced topics such as "design thinking," "engineering design process," "environmental education," "equity," and "maker education," along with sustained interest in "students" and "steam/steam education." This thematic progression highlights the continuous expansion of STEAM education to encompass new pedagogical strategies, technologies, and societal priorities.

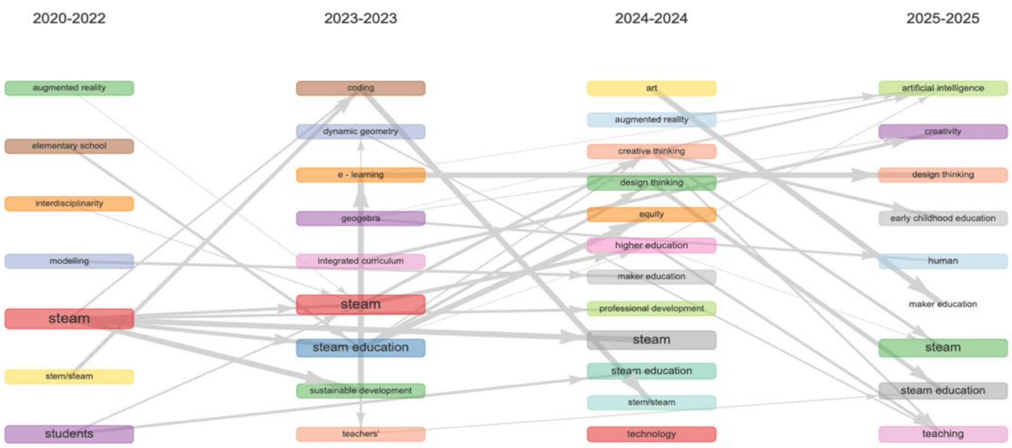

Figure 12: Thematic evolution of STEAM education

4. Discussion

This study presents an integrative bibliometric analysis of STEAM education research from 2016 to 2025, drawing on 1,097 SCOPUS-indexed journal articles. The discussion interprets key findings in relation to the study's objectives and research questions, highlighting theoretical implications, practical contributions, and directions for future inquiry. By synthesizing various bibliometric indicators, the study offers a multidimensional perspective on the intellectual, thematic, and collaborative structure of STEAM education. It bridges gaps in prior research by providing an updated, comprehensive mapping of the field. This section aims to contextualize the findings within broader academic and educational discourses.

The increasing trend in STEAM publication output, particularly between 2019 and 2024, confirms the field's dynamic expansion in response to global educational demands such as interdisciplinary competencies, technological fluency, and creativity (Tran et al., 2022). This upward trajectory reflects not only increased scholarly interest but also policy-driven mandates to reform curricula around integrative approaches. The high volume of publications during this period suggests a strong alignment between research agendas and educational needs. The slight decrease in publication volume in 2025 may represent a phase of consolidation or thematic redirection, a pattern consistent with maturing research fields (Rizki et al., 2022; Visser et al., 2021; Elwardany, 2025). Such fluctuations are common in fields undergoing conceptual refinement and methodological stabilization.

The prominence of specific journals—*Education Sciences*, *Thinking Skills and Creativity*, and *Sustainability* (Switzerland)—in disseminating STEAM research (see Table 2 and Figure 2) illustrates the field's consolidation around key publication outlets. These journals serve as platforms for interdisciplinary scholarship and foster the development of shared research priorities. Their editorial scopes accommodate diverse methodologies and theoretical lenses, making them attractive venues for STEAM-related work. The clustering of highly cited works within these outlets also reflects the intellectual coherence and citation visibility of STEAM research (Pandey, 2025; Si & Lai, 2024). Their impact is further evidenced by high total link strength and extensive cross-citation networks.

Analysis of author networks (figures 3 and 4) reveals strong global collaboration patterns and identifies key contributors, such as Lavicza, Herro, Kim, Quigley, and Bogner. These authors frequently co-author publications and engage in cross-institutional partnerships, which enhances the visibility and impact of their research. Their recurrent presence across highly cited studies signals intellectual leadership, while extensive co-authorship and international collaborations underscore the field's multidisciplinary and global orientation (Supriyadi et al., 2023; Tran et al., 2024). Such collaborations contribute to knowledge exchange, innovation diffusion, and the creation of scholarly communities. This finding aligns with broader trends in science mapping, where network centrality correlates with research influence.

Geographical collaboration and bibliographic coupling (figures 5 and 6) further highlight the centrality of the United States, China, and Spain in fostering research connectivity and output (Gonzales et al., 2025; Prahani et al., 2023). These countries not only contribute the highest volume of publications but also act as centers for cross-border academic exchange. Their institutional capacities, funding mechanisms, and policy frameworks likely support sustained engagement in STEAM research. Moreover, the presence of intercontinental links suggests a high degree of internationalization within the field. Such geographic patterns have implications for research equity, access to funding, and knowledge dissemination.

Keyword co-occurrence analysis (figures 7 and 8) reveals the thematic breadth of STEAM education, with a shift from traditional STEM priorities toward creativity, computational thinking, equity, and sustainability. This shift reflects a broader pedagogical reorientation toward learner-centered and socially responsive education. The rise of keywords such as "environmental education," "design thinking," and "equity" indicates the field's alignment with global educational challenges. It also shows how researchers are increasingly embedding STEAM education within real-world problem-solving frameworks. This thematic expansion reflects the field's responsiveness to educational innovation and global challenges (Rizki et al., 2022; Elwardany, 2025; Prada Núñez et al., 2024).

The evolution of research themes (figures 9–11) indicates a transition from foundational integration models (2016–2020) to complex pedagogical innovations (2021–2025), including game-based learning, digital transformation, and environmental education. These trends suggest that STEAM research is expanding to include a broader range of instructional strategies and target outcomes. The field has moved beyond basic integration to emphasize affective, cognitive, and social dimensions of learning. This shift is consistent with international calls for education to address societal needs and promote sustainability and equity. Collectively, these developments point to a maturing research agenda aligned with global policy and pedagogical trends (Supriyadi et al., 2023).

Three major implications emerged from this study. First, STEAM education is confirmed as a core innovation driver, aligned with global policy demands for interdisciplinary and adaptive learning (Aria & Cuccurullo, 2017; Nurfadilah et al., 2025). This role is reinforced by its growing visibility in national curricula and strategic research agendas. Second, identifying key authors, sources, and countries can guide strategic partnerships, policy formation, and resource allocation (Marín et al., 2021; Suprapto et al., 2024). Such data-driven strategies can foster inclusive and impactful scholarly ecosystems. Third, thematic diversification encourages curriculum innovation through the integration of digital tools, sustainability, and inclusive pedagogies (Aria et al., 2024; Bancong, 2024). These findings highlight STEAM's potential to influence educational design and practice at multiple levels.

This study's key contribution lies in its holistic mapping of STEAM education's intellectual and social structures. By integrating publication trends, citation networks, keyword co-occurrence, and thematic evolution, it addresses the fragmentation in previous reviews and provides a comprehensive overview useful to scholars and practitioners alike. The methodological approach combines descriptive, network, and trend analyses, offering a balanced and robust assessment. This integration of techniques enables a nuanced understanding of research dynamics across time and space. The application of robust bibliometric techniques and transparent methodological steps enhances the study's validity and reproducibility (Aria et al., 2024; Tran et al., 2024).

Nevertheless, several limitations should be acknowledged. The analysis is limited to SCOPUS-indexed articles, which may exclude relevant contributions from non-indexed sources or 'grey' literature. Furthermore, reliance on quantitative bibliometric indicators may overlook qualitative nuances of educational innovation. Temporal limitations (cut-off in early 2025) may also affect the accuracy of trend forecasts. The study also does not account for differences in citation behavior across disciplines, which could influence impact assessments. Future research could address these gaps by incorporating multi-database comparisons, mixed methods designs, and longitudinal tracking of emergent themes (Bancong, 2024; Nanda et al., 2025).

This study demonstrates that STEAM education research is a vibrant, evolving field characterized by global collaboration, conceptual innovation, and increasing societal relevance. The field continues to develop new themes in response to policy, technological, and pedagogical shifts. Continued monitoring of emerging topics, especially in areas such as equity, digital transformation, andsustainability, —will be vital to sustaining the field's impact and guiding educational policy and practice. The findings serve as a foundation for evidence-based curriculum design, professional development, and strategic research planning. As STEAM education grows in complexity and scope, bibliometric studies such as this one will remain crucial for charting its development.

5. Recommendations

Based on the findings of this bibliometric analysis on the evolution of STEAM education research from 2016 to 2025, this section provides targeted and actionable recommendations for key stakeholders, such as researchers, educators, and policymakers. These recommendations aim to translate global research trends into practical strategies that support innovation in educational theory, classroom practice, and policy development.

For researchers in the future, studies could explore emerging and underrepresented themes such as sustainability, educational equity, environmental education, and the integration of AI in STEAM learning. There is also a strong need for comparative and longitudinal studies that investigate how STEAM education is adopted and localized across different countries and regions. To ensure a more inclusive and comprehensive research landscape, researchers are encouraged to utilize multiple academic databases beyond SCOPUS, such as

Web of Science, ERIC, and national repositories. Additionally, to enhance the pedagogical relevance of bibliometric insights, it is recommended that scholars complement quantitative analyses with qualitative approaches, including classroom-based case studies and action research.

For educators, the study highlights the importance of implementing interdisciplinary curriculum models that blend scientific inquiry with creative expression through approaches such as *design thinking*, *maker education*, and *project-based learning*. Instructional design should focus on building essential 21st-century skills, including critical thinking, creativity, collaboration, and digital literacy. Continuous professional development is essential for equipping teachers with the knowledge and confidence to apply STEAM pedagogy, integrate assessment innovations, and align teaching practices with emerging educational priorities. Furthermore, educators can utilize the evolving research themes identified in this study—such as *computational thinking*, *gender equity*, and *early childhood STEAM*—as conceptual entry points for curriculum innovation and context-sensitive learning experiences.

For policymakers, it is recommended to promote national and regional curriculum frameworks that institutionalize interdisciplinary learning by embedding STEAM principles into the core educational structure. Policies should shift away from subject-siloed approaches and foster the integration of STEAM in meaningful and contextualized ways. Additionally, there is a pressing need to support teacher education and training initiatives that prioritize STEAM competencies across all education levels. Ensuring equitable access to STEAM resources and opportunities—particularly for rural, marginalized, or underserved communities—must be a policy priority. Finally, investment in research infrastructure, including data repositories, STEAM labs, and international partnerships, is essential to strengthen the global capacity for collaborative, innovative, and inclusive educational development.

6. Conclusion

This bibliometric analysis comprehensively maps the trajectory, intellectual structure, and collaborative dynamics of STEAM education research from 2016 to 2025. The study demonstrates that STEAM education has transitioned into a central domain of educational research, evidenced by a significant rise in scholarly output, a diverse network of influential authors and institutions, and a proliferation of interdisciplinary themes that reflect evolving global educational priorities. Notably, the findings reveal a shift from foundational curricular integration toward complex themes such as creativity, computational thinking, digital transformation, and sustainability, with increasing attention to equity and environmental education.

The dominance of leading journals and the emergence of robust international collaborations underscore the maturation and global reach of the field. Methodologically, the integration of advanced bibliometric mapping tools has enabled a nuanced, reproducible analysis that addresses prior gaps in the literature. Moving forward, the field is poised to further diversify and respond to emerging societal and technological challenges, with implications for curriculum design, teacher education, and educational policy. The contribution of this study lies in its unified and empirical synthesis of research trends, offering a strategic foundation for future innovation, collaboration, and evidence-based advancement in STEAM education.

7. References

Aktaş, M. C. (2022). Problem-posing research in mathematics education: A bibliometric analysis. *Journal of Pedagogical Research*. https://doi.org/10.33902/jpr.202217414

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Aria, M., Cuccurullo, C., D'Aniello, L., Misuraca, M., & Spano, M. (2024). Comparative science mapping: A novel conceptual structure analysis with metadata. *Scientometrics*, *129*(11), 7055–7081. https://doi.org/10.1007/s11192-024-05161-6

Bancong, H. (2024). The past and present of thought experiments' research at Glancy: bibliometric review and analysis. *Discover Education*, *3*(1), 142. https://doi.org/10.1007/s44217-024-00246-z

Bertrand, M. G., & Namukasa, I. K. (2020). STEAM education: Student learning and transferable skills. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 43–56. https://doi.org/10.1108/jrit-01-2020-0003

Caputo, A., & Kargina, M. (2021). A user-friendly method to merge Scopus and web of science data during bibliometric analysis. *Journal of Marketing Analytics*, *10*(1), 82–88. https://doi.org/10.1057/s41270-021-00142-7

Chandir, H., & Görur, R. (2021). Unsustainable measures? Assessing global competence in PISA 2018. *Education Policy Analysis Archives*, *29*(August-December), 122. https://doi.org/10.14507/epaa.29.4716

Chen, S., & Ding, Y. (2023). Assessing the psychometric properties of STEAM competence in primary school students: a construct measurement study. *Journal of Psychoeducational Assessment*, *41*(7), 796–810. https://doi.org/10.1177/07342829231186685

Cocha, T. B., & Chocholakova, A. S. (2023). Example of good practice for supporting STEAM in technical subjects learning. *Journal of Technology and Information*, *15*(1), 64–77. https://doi.org/10.5507/jtie.2023.002

Conradty, C., & Bogner, F. X. (2019). From STEM to STEAM: Cracking the code? How creativity & motivation interacts with inquiry-based learning. *Creativity Research Journal*, *31*(3), 284–295. https://doi.org/10.1080/10400419.2019.1641678

Deák, C., & Kumar, B. (2024). A systematic review of STEAM education's role in nurturing digital competencies for sustainable innovations. *Education Sciences*, *14*(3), 226. https://doi.org/10.3390/educsci14030226

Deng, Y., Ong, T. S., & Senik, R. (2024). Trick or treat? A bibliometric literature review of corporate social responsibility and earnings management. *Corporate Social Responsibility and Environmental Management*, *31*(5), 4361–4383. https://doi.org/10.1002/csr.2806

Dienana, A., Rizqia, A. S., Sopian, A., & Abdullah, M. Y. (2024). Pedagogical stylistic research: A bibliometric analysis using Vosviewer and Biblioshiny R from 2013-2023. *Tamaddun*, *23*(1), 123–134. https://doi.org/10.33096/tamaddun.v23i1.696

Elwardany, M. (2025). Bibliometric analysis of research trends in STEAM boiler efficiency improvement. *International Journal of Thermodynamics*, *28*(2), 115–128. https://doi.org/10.5541/ijot.1608741

Furstenau, L. B., Rabaioli, B., Sott, M. K., Cossul, D., Bender, M. S., Farina, E. M. J. de M., Filho, F. N. B., Severo, P., Dohan, M. S., & Bragazzi, N. L. (2021). A bibliometric network analysis of coronavirus during the first eight months of COVID-19 in

2020. *International Journal of Environmental Research and Public Health*, *18*(3), 952. https://doi.org/10.3390/ijerph18030952
Gonzales, L. S., Salazar, G. O., Negrete, P. Y. Q., & Vargas, C. G. A. P. (2025). Integrating STEAM in primary education: A systematic review from 2010 to 2024. *Journal of Educational and Social Research*, *15*(2), 343–359. https://doi.org/10.36941/jesr-2025-0064
Habibi, M. A. M. (2023). Effect of the STEAM Method on children's creativity. *Jurnal Penelitian Pendidikan Ipa*, *9*(1), 315–321. https://doi.org/10.29303/jppipa.v9i1.2378
Herro, D., & Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: Implications for teacher educators. *Professional Development in Education*, *43*(3), 416–438. https://doi.org/10.1080/19415257.2016.1205507
Herro, D., Quigley, C., Andrews, J., & Delacruz, G. (2017). Co-measure: Developing an assessment for student collaboration in STEAM activities. *International Journal of STEM Education*, *4*(1). https://doi.org/10.1186/s40594-017-0094-z
Hsiao, P.-W., & Su, C.-H. (2021). A study on the impact of STEAM education for sustainable development courses and its effects on student motivation and learning. *Sustainability*, *13*(7), 3772. https://doi.org/10.3390/su13073772
Joseph, J., Jose, A. S., Ettaniyil, G. G., Jasimudeen, S., & Jose, J. (2024). Mapping the landscape of electronic health records and health information exchange through bibliometric analysis and visualization. *Cureus*. https://doi.org/10.7759/cureus.59128
Joseph, J., Jose, J., Jose, A. S., Ettaniyil, G. G., Cyriac, J., Sebastian, S. A., & Joseph, A. P. (2024). Quantitative insights into outcome-based education: A bibliometric exploration. *International Journal of Evaluation and Research in Education (Ijere)*, *13*(6), 4030. https://doi.org/10.11591/ijere.v13i6.29272
Lam, H., Chuong, A., Thien, N. H., Thị, T., Hanh, T., & Do, C. (2023). Assessing the competence of early childhood education students at teacher education universities in Vietnam in terms of implementing STEAM education. *European Journal of Contemporary Education*, *12*(2). https://doi.org/10.13187/ejced.2023.2.385
Lan Anh, D. (2024). Developing competency framework for organizing STEAM education activities for early childhood education students. *Journal of Science Educational Science*, 109–118. https://doi.org/10.18173/2354-1075.2024-0068
Lee, U., Han, A., Lee, J., Lee, E., Kim, J., Kim, H, & Lim, C. (2024). Prompt aloud! Incorporating image-generative AI into STEAM class with learning analytics using prompt data. *Education and Information Technologies*, *29*(8), 9575–9605. https://doi.org/10.1007/s10639-023-12150-4
Li, J., Luo, H., Zhao, L., Zhu, M., Ma, L., & Liao, X. (2022). Promoting STEAM education in primary school through cooperative teaching: A design-based research study. *Sustainability*, *14*(16), 10333. https://doi.org/10.3390/su141610333
Li, K. C., & Wong, B. T.-M. (2023). Personalisation in STE(A)M education: a review of literature from 2011 to 2020. *Journal of Computing in Higher Education*, *35*(1), 186–201. https://doi.org/10.1007/s12528-022-09341-2
Li, Y. (2023). From STEM education to STEAM education-the new role of art education. *Frontiers in Art Research*, *5*(5). https://doi.org/10.25236/far.2023.050508
Ma, L., Luo, H., Liao, X., & Li, J. (2022). Impact of gender on STEAM education in elementary school: From individuals to group compositions. *Behavioral Sciences*, *12*(9). https://doi.org/10.3390/bs12090308
Marín, J. A. M., Guerrero, A. J. M., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in Education: A Bibliometric Analysis of Performance and Co-Words in Web of

Science. *International Journal of Stem Education*, *8*(1). https://doi.org/10.1186/s40594-021-00296-x

Munawar, M., Setyoadi, Y., Luthfy, P. A., & Prasetyawati, D. (2024). Supporting and inhibiting factors of outdoor STEAM learning in early childhood education. *Kne Social Sciences*. https://doi.org/10.18502/kss.v9i6.15289

Nanda, A. R., Nurnawaty, Mansida, A., & Bancong, H. (2025). A bibliometric analysis of trends in rainfall-runoff modeling techniques for urban flood mitigation (2005–2024). *Results in Engineering*, *26*, 104927. https://doi.org/10.1016/j.rineng.2025.104927

Ng, A., Kewalramani, S., & Kidman, G. (2022). Integrating and navigating STEAM (inSTEAM) in early childhood education: An integrative review and inSTEAM conceptual framework. *Eurasia Journal of Mathematics Science and Technology Education*, *18*(7), em2133. https://doi.org/10.29333/ejmste/12174

Nurfadilah, N., Bancong, H., Saad, R., & Fiskawarni, T. H. (2025). Direction of gamification in science education: Literature review and indexed bibliography. *International Journal of Learning, Teaching and Educational Research*, *24*(4), 568–591. https://doi.org/10.26803/ijlter.24.4.26

Pandey, A. (2025). Artificial intelligence models as a guide to conduct bibliometric analysis of research on STEAM learning. *Revista Review Index Journal of Multidisciplinary*, *5*(1), 22–29. https://doi.org/10.31305/rrijm2025.v05.n01.003

Phuong, H. Y., Phan, Q. T., & Le, T. T. (2023). The effects of using analytical rubrics in peer and self-assessment on EFL students' writing proficiency: A Vietnamese contextual study. *Language Testing in Asia*, *13*(1). https://doi.org/10.1186/s40468-023-00256-y

Phương, N. L., Le, H. T. T., Linh, N. Q., Thảo, T. T. P., Pham, H.-H. T., Giang, N. T., & Thuy, V. T. (2023). Implementation of STEM education: A Bibliometrics analysis from case study research in Scopus database. *Eurasia Journal of Mathematics Science and Technology Education*, *19*(6), em2278. https://doi.org/10.29333/ejmste/13216

Prada Nunez, R., Penaloza Tarazona, M. E., & Rodríguez Moreno, J. (2024). Trends and challenges of integrating the STEAM approach in education: A Scopus literature review. *Data and Metadata*, *3*. https://doi.org/10.56294/dm2024.424

Prahani, B. K., Nisa, K., Nurdiana, M. A., Kurnianingsih, E., Amiruddin, M. Z. Bin, & Sya'roni, I. (2023). Analyze of STEAM education research for three decades. *Journal of Technology and Science Education*, *13*(3), 837. https://doi.org/10.3926/jotse.1670

Quigley, C. F., & Herro, D. (2016). "Finding the joy in the unknown": Implementation of STEAM teaching practices in middle school science and math classrooms. *Journal of Science Education and Technology*, *25*(3), 410–426. https://doi.org/10.1007/s10956-016-9602-z

Razi, A., & Zhou, G. (2022). STEM, iSTEM, and STEAM: What is next? *International Journal of Technology in Education*, *5*(1), 1–29. https://doi.org/10.46328/ijte.119

Rizki, I. A., Setyarsih, W., & Suprapto, N. (2022). A bibliometric study of the project-based learning-STEAM model on students' critical thinking and scientific literacy. *Jurnal Penelitian Ilmu Pendidikan*, *15*(1). https://doi.org/10.21831/jpipfip.v15i1.45403

Sandu, A., Cotfas, L., Delcea, C., Crăciun, L., & Molănescu, A. G. (2023). Sentiment analysis in the age of COVID-19: A bibliometric perspective. *Information*, *14*(12), 659. https://doi.org/10.3390/info14120659

Santi, K., Sholeh, S. M., Irwandani, İ., Alatas, F., Rahmayanti, H., Ichsan, I. Z., & Rahman, Md. M. (2021). STEAM in environment and science education: analysis and bibliometric mapping of the research literature (2013–2020). *Journal of Physics Conference Series*, *1796*(1), 012097. https://doi.org/10.1088/1742-6596/1796/1/012097

Shukshina, L. V, Gegel, L. A., Erofeeva, M. A., Levina, I. D., Chugaeva, U. Y., & Nikitin, O. D. (2021). STEM and STEAM education in Russian education: Conceptual framework. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(10), 1–14. https://doi.org/10.29333/ejmste/11184

Si, H., & Lai, R. (2024). Analysis of the current status of STEAM education research in China in the past decade based on CiteSpace visualization. *Region - Educational Research and Reviews*, *6*(8), 112. https://doi.org/10.32629/rerr.v6i8.2503

Sit, M. (2022). Exploring the knowledge and experience of childhood education teachers on STEAM education in Indonesia. *Educational Administration: Theory and Practice*, *28*(2), 57–65. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85136317907&partnerID=40&md5=ab9e1bd8d2b4ee5331554fb3208f87ba

Soroko, N. V, Mykhailenko, L. A., Rokoman, O. G., & Zaselskiy, V. I. (2020). Educational Electronic Platforms for STEAM-oriented Learning Environment at General Education School. *Cte Workshop Proceedings*, *7*, 462–473. https://doi.org/10.55056/cte.386

Suganda, E., Latifah, S., Irwandani, İ., Sari, P. M., Rahmayanti, H., Ichsan, I. Z., & Rahman, Md. M. (2021). STEAM and Environment on Students' Creative-Thinking Skills: A Meta-Analysis Study. *Journal of Physics Conference Series*, *1796*(1), 012101. https://doi.org/10.1088/1742-6596/1796/1/012101

Suprapto, N., Rizki, I. A., & Kholiq, A. (2024). Exploring the cultural fabric: A study on Indonesia's unique architectural marvels for ethno-STEAM education system. *TEM Journal*, *13*(3), 2249–2255. https://doi.org/10.18421/TEM133-52

Supriyadi, E., Turmudi, T., Dahlan, J. A., & Juandi, D. (2023). Publication trends from STEAM in education from Scopus database: bibliometric analysis. *Jurnal Penelitian Pendidikan Ipa*, *9*(6), 104–111. https://doi.org/10.29303/jppipa.v9i6.3576

Thi Thuy Linh, D., Thi Ngoc Tu, P., Thi Quynh Thi, H., Thi Hieu, N., Thi Luan, N., & Viet Nhi, T. (2024). Bibliometric analysis of publications on STEM and STEAM education in early childhood from Southeast Asian countries. *Vinh University Journal of Science*, *53*(Special Issue 1), 17–30. https://doi.org/10.56824/vujs.2024.htkhgd01

Thuneberg, H. M., Salmi, H. S., & Bogner, F. X. (2018). How creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module. *Thinking Skills and Creativity*, *29*, 153–160. https://doi.org/10.1016/j.tsc.2018.07.003

Tran Thi Minh, T., Nguyen Minh, P., Hoang Thi Le, Q., & Dao Thi Phuong, L. (2022). Designing STEAM activities to increase the participation of children with disabilities in inclusive kindergarten. *Journal of Science Educational Science*, *67*(5A), 60–70. https://doi.org/10.18173/2354-1075.2022-0120

Tran, V. N., Duong, T. T. L., Phan, T. N. T., Huynh, T. Q. T., Nguyen, T. H., & Nguyen, T. L. (2024). STEAM in early childhood education between 2013-2023: A bibliometric analysis of Scopus database. *Dong Thap University Journal of Science*, *13*(7), 18–27. https://doi.org/10.52714/dthu.13.7.2024.1334

Van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, *111*(2), 1053–1070. https://doi.org/10.1007/s11192-017-2300-7

Visser, M., van Eck, N. J., & Waltman, L. (2021). Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic. *Quantitative Science Studies*, *2*(1), 20–41. https://doi.org/10.1162/qss_a_00112