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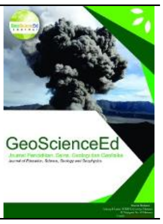

Trends in STEAM Research in Science Education from 2016 to 2025: A Bibliometric Analysis and Systematic Literature Review

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Abstract: This study aimed to analyze research trends in STEAM research in science education from 2016 to 2025 by combining bibliometric analysis and a systematic literature review (SLR). Bibliometric data were retrieved from the Dimensions database using the keyword STEAM Research in Science Education. The initial search in the full data field yielded 281,366 documents; however, after restricting the search to the title and abstract fields, 1,412 publications were obtained and analyzed using VOSviewer. In addition, an SLR was conducted on 30 articles published in reputable Scopus-indexed journals. The findings reveal a significant increase in STEAM-related publications in science education, particularly after 2022, when the annual number of publications rose sharply from 127 in 2022 to 402 in 2025. This trend indicates growing academic interest in integrative, creative, and contextual learning approaches. Keyword analysis shows the dominance of general terms such as student, education, learning, system, and science, while the network visualization demonstrates strong linkages between pedagogical and applied clusters. However, the density and overlay visualizations indicate that the integration of STEAM with culture, indigenous knowledge, and ethnoscience remains peripheral. The SLR findings further show that STEAM research in science education has mainly focused on twenty-first-century skills, scientific literacy, creativity, and teacher implementation support, but remain fragmented across contexts, educational levels, and outcome variables. Therefore, this study confirms that although STEAM has developed rapidly in science education, further research is still needed to systematically integrate publication trends, thematic structures, methodological approaches, and cultural or local dimensions to strengthen future directions of STEAM research.

Keywords: STEAM; science education; bibliometric analysis; systematic literature review.

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Introduction

Twenty-first-century educational developments require science learning to move beyond isolated concept mastery toward enabling students to understand, connect, and apply scientific knowledge in real-world contexts. In early discussions, Breiner et al. (2012) argued that STEM is not merely a combination of several subjects, but an effort to redefine educational goals so that they are more relevant to the needs of modern society. This view was reinforced by Gresnigt et al. (2014), who showed that integrated curricula provide greater opportunities for students to recognize the connections between concepts and their applications. In K–12 education, English (2016) positioned STEM integration as an important agenda,

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while Kelley and Knowles (2016) developed the conceptual framework of integrated STEM that continues to serve as a major reference in science education.

As the field has developed, STEM has expanded into STEAM through the inclusion of the Arts as part of instructional design. In their review, Perignat & Katz-Buonincontro (2019) explained that the addition of the arts is not intended as a decorative supplement, but rather as a means of strengthening creativity, communication, design, and innovative thinking in the learning process. This perspective is consistent with the findings of Filipe et al. (2024), who demonstrated that integrated STEAM contributes to the development of students' creativity. Accordingly, STEAM broadens the orientation of science education from mere content mastery to the development of students' ability to design solutions, build representations, and communicate scientific ideas more creatively.

In the context of science education, the relevance of STEAM becomes even stronger because science itself is grounded in inquiry, experimentation, modeling, evidence-based argumentation, and problem solving. Martín-Páez et al. (2019) emphasized that discussions of STEM education are always related to how concepts and practices are meaningfully connected. Meanwhile, Thibaut et al. (2018) showed that integrated STEM requires instructional designs that deliberately connect multiple disciplines within problem-solving contexts. Therefore, the implementation of STEAM in science education should not be assessed solely in terms of the creative products students produce, but also in terms of the extent to which they engage in scientific processes such as observing, formulating questions, testing ideas, interpreting data, and drawing conclusions.

A growing body of empirical studies has shown that STEAM integration in science education contributes positively to learning outcomes. In the topic of light and optics, Wandari et al. (2018) found that STEAM-based learning improved students' conceptual understanding and creativity. In chemistry learning, Rahmawati et al. (2019) reported that STEAM integration could enhance students' critical and creative thinking skills, while Rahmawati et al. (2020) demonstrated that STEAM projects supported the development of critical thinking. In project-based science learning, Adriyawati et al. (2020) reported improvements in students' scientific literacy through the context of alternative energy. Similar findings were presented by Anggraeni and Suratno (2021) and Suryanti et al. (2024), who showed that STEAM-project-based learning can improve critical thinking skills and scientific literacy. At the level of instructional design, English & King (2019) as well as Lupión-Cobos et al. (2022) demonstrated that STEM/STEAM integration in science learning promotes stronger connections among concepts, design, and authentic learning experiences.

In addition to its interdisciplinary nature, the development of STEAM in science education is becoming increasingly relevant when linked to local-context or ethnoscience-based approaches. This approach enables scientific concepts to be learned through cultural experiences, community practices, and local knowledge embedded in students' everyday lives. Hall & Tengan (2024) showed that the integration of local knowledge into science curricula contributes to cultural sustainability and enhances the relevance of learning. This finding was reinforced by Cheruvalath et al. (2025), who argued that science learning through local knowledge systems helps make science more contextual, meaningful, and closely related to students' social realities. Thus, in science education, ethnoscience functions not only as an introductory context, but also as a bridge that connects school science with community-based lived practices.

Despite its strong potential, the implementation of STEAM in science education still faces conceptual and practical challenges. From a conceptual standpoint, Margot & Kettler (2019) found that teachers' perceptions of STEM integration vary considerably in terms of purpose, depth of integration, and implementation strategies. More recent work by Portillo-Blanco et al. (2024) also confirmed that integrated STEM still reflects a diversity of principles and characteristics and therefore has not yet reached a fully established operational consensus. In practice, Thibaut et al. (2018) found that teachers' attitudes toward integrated STEM are influenced by school context and personal factors. In terms of professional development, Estapa and Tank (2017) highlighted the importance of pedagogical support grounded in design challenges, while Lo (2021) showed that teacher professional development is a key prerequisite for effective STEM implementation. This is consistent with the findings of Breda et al. (2023) and Spyropoulou et al. (2025), who showed that teachers generally believe in the value of STEAM but still require substantial support in planning, collaboration, and assessment.

The increasing attention given to STEAM is also reflected in the growth of scientific publications over the past decade. Through a systematic review of journal publications, Li et al. (2020) showed that STEM research has grown rapidly and has become increasingly established as a global field of study. In the domain of STEAM, Marín-Marín et al. (2021) mapped research performance and keyword co-occurrence in the Web of Science database, revealing the widening development of themes in this field. Furthermore, Li et al. (2022) identified trends in high-impact empirical studies in STEM education, while Yim et al. (2025) and Amanova et al. (2025) showed that STEAM research continues to expand across educational levels and implementation contexts. These findings indicate that STEAM in science education has grown substantially, yet its knowledge structure still requires more focused mapping.

Previous studies have mapped STEAM research broadly across educational levels, disciplines, and implementation contexts. However, none has specifically focused on the development of STEAM within science education using a combined bibliometric–SLR approach. This gap is important because science education has distinctive epistemic characteristics, including its emphasis on scientific inquiry, experimentation, modeling, evidence-based reasoning, and scientific literacy. Therefore, a domain-specific mapping is needed to identify how STEAM research has developed within science education, including its dominant themes, methodological approaches, research contexts, learning outcomes, and remaining gaps.

Based on the discussion above, the study entitled "Trends in STEAM Research in Science Education from 2016 to 2025: A Bibliometric Analysis and Systematic Literature Review" is important to conduct. The period 2016–2025 was selected because it represents a phase of rapid development in this field, beginning with the strengthening of the conceptual framework and followed by the expansion of empirical and bibliometric studies. The novelty of this study lies in its domain-specific and integrated mapping of STEAM research in science education. Specifically, the bibliometric analysis provides a macro-level overview of publication growth, keyword co-occurrence, and thematic structures, while the systematic literature review provides a micro-level synthesis of research contexts, methodological approaches, learning outcomes, and unresolved gaps. Through this integrated approach, this study is expected to provide a more comprehensive understanding of the development of STEAM research in science education and to offer clearer directions for future research.

Method

Research Design

This study employed a mixed review design by combining bibliometric analysis and a systematic literature review (SLR) to examine research trends in STEAM Research in Science Education from 2016 to 2025. Bibliometric analysis was used to map the quantitative development of publications, thematic relationships, and topic trends, while the SLR was conducted to qualitatively examine research focuses, methodological characteristics, study contexts, and the major findings reported in the most relevant articles.

Data Source and Search Strategy

The bibliometric data was retrieved from the Dimensions database. The search was conducted using the keyword "STEAM Research in Science Education" with a publication year range of 2016–2025. In the initial stage, the search was performed using the full data option, which yielded 281,366 documents under the publications category. However, to improve the relevance of the dataset to the focus of the study, the search was then restricted to the occurrence of the keyword in the title and abstract fields only. After applying this restriction, the number of retrieved documents was reduced to 1,412 publications. These data were then saved and exported for bibliometric analysis.

Bibliometric Analysis

The bibliometric analysis was conducted using VOSviewer to map the conceptual structure and thematic distribution of STEAM research in science education. Bibliographic data were exported from the Dimensions database using a title and abstract search for the period 2016–2025, resulting in 1,412 publications. Before visualization, the dataset underwent data selection and cleaning, including checking metadata consistency, removing duplicate records when necessary, and standardizing similar terms to improve the accuracy of the bibliometric map.

The analysis was conducted using term co-occurrence analysis based on terms extracted from the title and abstract fields. The unit of analysis was terms, and the counting method was set to binary counting, meaning that the occurrence of a term was counted once per document. The minimum occurrence threshold was set at 49, so only terms appearing in at least 49 documents were included in the final visualization. Based on this threshold and the relevance score generated by VOSviewer, 100 terms were selected and analyzed further. The co-occurrence network was normalized using the association strength method. Clustering was performed using the VOSviewer clustering algorithm with a clustering resolution of 1.00 and a minimum cluster size of 1.

The results were visualized through network visualization and density visualization. Network visualization was used to identify relationships among terms and thematic clusters, while density visualization was used to show the intensity of term occurrence within the field. These parameters were applied to ensure that the bibliometric mapping provided a transparent and reproducible overview of the knowledge structure of STEAM research in science education.

Systematic Literature Review Procedure

To complement the bibliometric findings, this study also employed a systematic literature review (SLR) of the most relevant articles. The SLR followed four main stages: identification, screening, eligibility, and inclusion. In the identification stage, the initial pool of documents was obtained from the database search based on the predefined keyword and publication period. In the screening stage, documents were filtered according to document type and initial relevance to the topic. In the eligibility stage, abstracts and full texts were examined more closely to ensure their substantive relevance to STEAM Research in Science Education. In the inclusion stage, 30 journal articles published in reputable Scopus-indexed journals were selected for in-depth analysis.

Inclusion and Exclusion Criteria

The inclusion criteria in this study were as follows: (1) the article was published between 2016 and 2025; (2) the document type was a journal article; (3) the article was published in a reputable Scopus-indexed journal; (4) the article had direct relevance to the topic of STEAM Research in Science Education; and (5) the article was available in full text or at least provided sufficient information for analysis. The exclusion criteria included: (1) documents other than journal articles, such as conference proceedings, books, book chapters, editorials, and brief notes; (2) articles that did not directly address STEAM in the context of science education; (3) duplicate documents or repeated metadata; and (4) articles that did not provide sufficient substantive information for analysis.

SLR Data Analysis

The 30 selected articles were then analyzed qualitatively by focusing on several main aspects: (1) research themes, (2) research approaches or designs, (3) educational levels and contexts, (4) variables or focal issues, and (5) major findings.

Trustworthiness of the Analytical Procedure

The integration of bibliometric analysis and SLR in this study was intended to increase both the breadth and depth of interpretation. Bibliometric analysis provided a macro-level overview of publication structure and development, while the SLR offered a micro-level understanding of the content and direction of the key studies. Therefore, the two approaches complemented each other in producing a more comprehensive mapping of research trends in STEAM Research in Science Education during the 2016–2025 period.

Result and Discussion

The findings of the bibliometric analysis and systematic literature review provide a comprehensive overview of research trends in *STEAM Research in Science Education* from 2016 to 2025. The bibliometric results, derived from 1,412 publications indexed in the Dimensions database and analyzed using VOSviewer, reveal patterns of publication growth, thematic clustering, and keyword relationships within the field. To complement this macro-level mapping, the systematic literature review of 30 articles published in reputable Scopus-indexed journals offers deeper insights into dominant research themes, methodological approaches, educational contexts, and key findings reported in prior studies. The integration of these approaches enables a more comprehensive interpretation of both the quantitative development and the substantive directions of STEAM research in science education, including emerging issues and existing research gaps.

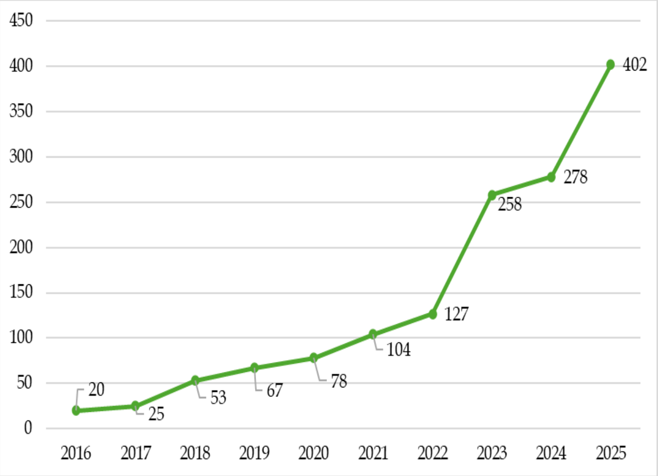

Figure 1. Publication Dynamics Using the Keyword STEAM Research in Science Education Based on Title and Abstract for the Period 2016–2025 (Data Source: Dimensions)

Figure 1 illustrates the publication dynamics of STEAM research in science education based on title and abstract searches in the Dimensions database from 2016 to 2025. The trend shows a consistent increase in the number of publications over time, beginning with only 20 publications in 2016 and rising gradually to 127 publications in 2022. After 2022, the growth accelerated markedly, with publications increasing from 127 in 2022 to 258 in 2023, 278 in 2024, and 402 in 2025. This represents an increase of approximately **216.5%** from 2022 to 2025, indicating that the annual publication output more than tripled during this period. This pattern suggests that 2022 marked an acceleration point in the development of STEAM research within science education. This trend is consistent with earlier findings showing that STEM/STEAM research has expanded rapidly as a global field of study, driven by the growing demand for interdisciplinary, innovative, and twenty-first-century-relevant learning approaches (Li et al., 2020). In addition, the sharp rise in recent years indicates stronger academic attention to the integration of STEAM in education, as also reflected in bibliometric studies highlighting the expansion of themes and research directions in STEAM across diverse educational contexts (Marín-Marín et al., 2021). Overall, this trend demonstrates that STEAM in science education has evolved from a relatively limited topic into a rapidly growing and increasingly established field of research.

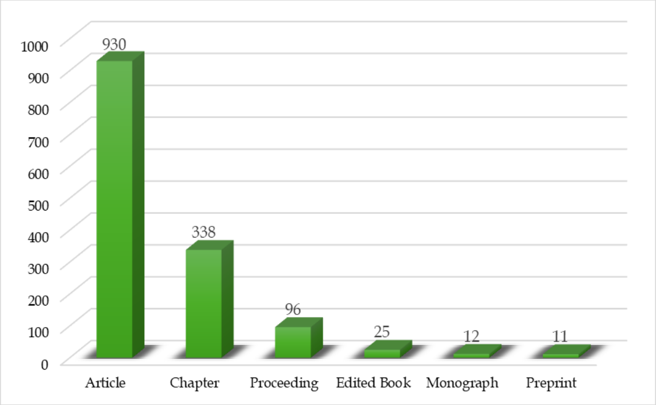

Figure 2. Publication Type (Data Source: Dimensions)

Figure 2 shows that the most dominant publication type in STEAM Research in Science Education is the article, with 930 documents, far exceeding chapters (338), proceedings (96), edited books (25), monographs (12), and preprints (11).

The dominance of journal articles suggests that the development of STEAM research in science education is disseminated primarily through formal scholarly publication channels that reflect a more established academic process. In bibliometric studies, journal articles are commonly regarded as the principal unit of scholarly communication because they are more stable, standardized, and representative of the development of a field than other publication formats (Donthu et al., 2021; Zupic & Čater, 2015). This pattern also indicates that STEAM in science education is becoming increasingly consolidated as an academic field, since its knowledge base is built predominantly through peer-reviewed journal publications. Such a tendency is consistent with recent synthesis studies in STEAM and integrated STEM, which generally rely on journal articles as the primary source for mapping research themes, approaches, and directions of development (Portillo-Blanco et al., 2024; Yim et al., 2025).

Table 1. STEAM Researchers Based on Number of Publications According to Dimensions Data

No.	Name	Organization, Country	Publications	Citations	Citations mean
1	Zsolt Lavicza	Johannes Kepler University of Linz, Austria	11	84	7.64
2	Fenny Roshayanti	Universitas PGRI Semarang, Indonesia	6	43	7.17
3	Pablo Dúo Dúo-Terrón	University of Granada, Spain	6	303	50.50
4	Eko Hariyono	State University of Surabaya, Indonesia	6	23	3.83
5	Cassie F Quigley	University of Pittsburgh, United States	5	400	80.00
6	Vincentas Lamanauskas	Vilnius University, Lithuania	5	21	4.20
7	Nadi Suprapto	State University of Surabaya, Indonesia	5	7	1.40
8	Armida De La Garza	University College Cork, Ireland	5	4	0.80
9	Billy Tak-Ming Wong	Hong Kong Metropolitan University	5	49	9.80
10	Nizar Alam Hamdani	Universitas Garut, Indonesia	5	7	1.40
11	Binar Kurnia Prahani	State University of Surabaya, Indonesia	5	16	3.20
12	Danielle C Herro	Clemson University, United States	5	400	80.00
13	Felixberto Mendoza Mercado	Enverga University, Philippines	5	19	3.80
14	Immaculate Kizito Namukasa	University of Western Ontario, Canada	4	179	44.75
15	Yves Kreis	University of Luxembourg, Luxembourg	4	40	10.00
16	Yuli Rahmawati	State University of Jakarta, Indonesia	4	81	20.25
17	Hao-Zhi Bian	Harbin Engineering University, China	4	2	0.50
18	Geison Jader Mello	Instituto Federal de Educação, Ciência e Tecnologia de Mato Grosso, Brazil	4	2	0.50
19	Ileana Maria Rosa Greca	University of Burgos, Spain	4	38	9.50
20	Kerry Anne Chappell	University of Exeter, United Kingdom	4	42	10.50

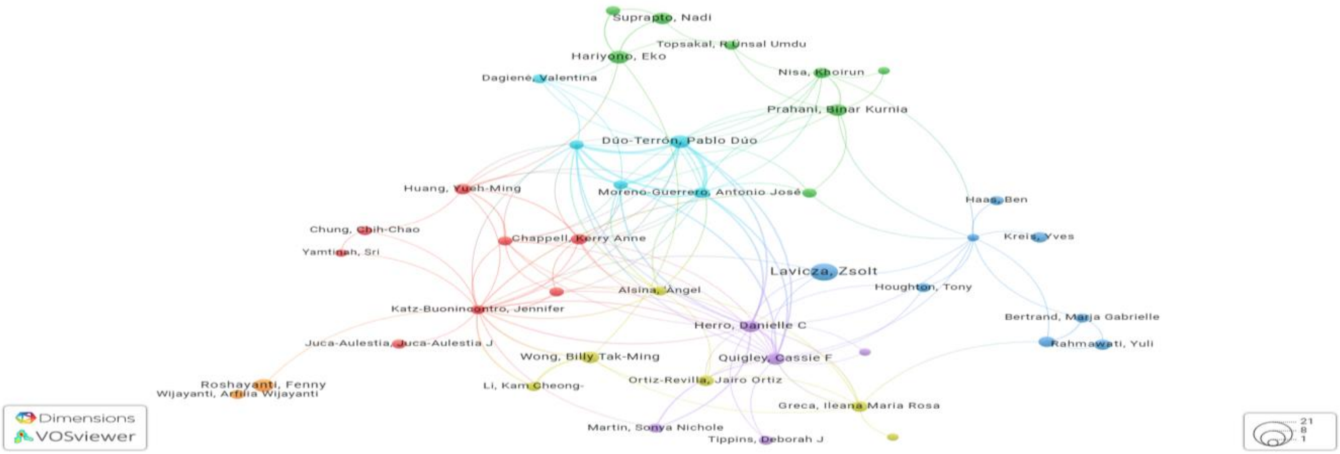

Figure 3. Collaboration Network of STEAM Researchers Based on Bibliometric Analysis (VOSviewer–Dimensions AI)

Table 1 and Figure 3 jointly demonstrate that publication productivity is not always identical to centrality within the collaboration network; rather, both indicators complement each other in explaining the research structure of *STEAM Research in Science Education*. According to Table 1, Zsolt Lavicza ranks as the most productive researcher with 11 publications, while Pablo Dúo Dúo-Terrón, Fenny Roshayanti, and Eko Hariyono follow with 6 publications each. However, when these data are interpreted alongside Figure 3, it becomes clear that some researchers are not only productive but also function as key nodes within the collaboration network. Zsolt Lavicza appears in a relatively central position and is linked to authors across different clusters, suggesting a bridging role between research groups. Similarly, Pablo Dúo Dúo-Terrón appears to have a broad and strong collaboration network, which is consistent with his high citation performance of 303 citations and a mean of 50.50 citations per publication. At the same time, the Indonesian cluster, including Nadi Suprapto, Eko Hariyono, and Binar Kurnia Prahani, reflects a relatively strong pattern of institutional or regional collaboration. Interestingly, researchers such as Cassie F. Quigley and Danielle C. Herro, although each produced only 5 publications, achieved 400 citations and an average of 80.00 citations per publication, indicating that academic influence is not determined solely by publication quantity, but also by the quality of the work and its position within collaboration networks. Overall, the combined reading of Table 1 and Figure 3 confirms that the landscape of STEAM research in science education is shaped by the interplay of scientific productivity, citation impact, and collaborative intensity, which together reveal the knowledge structure and academic networking dynamics of the field (Donthu et al., 2021; Van Eck & Waltman, 2010; Zupic & Čater, 2015).

Table 2. Frequently Occurring Terms in the Initial VOSviewer Extraction, Including Education-Related and Cross-Domain Terms

No.	Term	Occurrence	Relevance
1	Artificial intelligence	193	2.92
2	Higher education	76	2.59
3	Hydrogen production	82	2.57
4	Hydrogen	112	2.40
5	Evaporator	125	2.39
6	Carbon	106	2.32
7	Biomass	115	2.31
8	Pjbl	67	2.26
9	Catalyst	256	2.06
10	Surface	125	2.01
11	Storage	108	1.95
12	Stability	240	1.88
13	Efficiency	256	1.85
14	Control group	72	1.78
15	Waste	221	1.76
16	Essential oil	61	1.75
17	Experimental group	71	1.73
18	Emission	254	1.63
19	Systematic review	81	1.56
20	Environmental impact	73	1.53
21	Stem education	104	1.52
22	Early childhood education	49	1.50
23	Training	185	1.48
24	Significant difference	52	1.47
25	Energy	288	1.44
26	Stem	194	1.42
27	Optimization	192	1.38
28	Cycle	158	1.35
29	Critical thinking	79	1.27
30	Sustainable development	100	1.23

No.	Term	Occurrence	Relevance
31	Practitioner	110	1.19
32	Competency	143	1.18
33	Slr	54	1.13
34	Mathematics	212	1.12
35	Teacher	541	1.09
36	Skill	444	1.08
37	Questionnaire	116	1.08
38	Treatment	241	1.07
39	Production	461	1.07
40	Condition	434	1.06
41	School	248	1.02
42	Education	936	1.00
43	Learning	578	0.99
44	Class	128	0.92
45	Student	1349	0.91
46	Program	241	0.91
47	Curriculum	101	0.91
48	Product	278	0.89
49	Person	129	0.88
50	Educator	113	0.88
51	Advantage	110	0.88
52	Scenario	100	0.88
53	Climate change	94	0.86
54	Simulation	149	0.85
55	Gender	53	0.85
56	Inquiry	79	0.84
57	Society	133	0.83
58	Motivation	145	0.82
59	Perception	117	0.81
60	Book	424	0.81
61	Plant	231	0.80
62	Attitude	137	0.78
63	Creativity	171	0.77
64	Engagement	258	0.76
65	Transition	178	0.76
66	Test	293	0.75
67	Project	323	0.75
68	Structure	322	0.75
69	Indonesia	83	0.74
70	Capacity	197	0.74
71	Industry	323	0.71
72	Theme	106	0.70
73	World	179	0.70
74	Life	187	0.69
75	Course	125	0.69
76	Policymaker	94	0.69
77	Learner	112	0.67
78	Child	226	0.67
79	Action	138	0.66
80	Performance	610	0.65
81	Implementation	285	0.65
82	Increase	183	0.63
83	Culture	157	0.60
84	Participant	158	0.59
85	Community	247	0.57
86	Safety	102	0.56
87	Region	175	0.55
88	Combination	85	0.54
89	Interview	175	0.54
90	Collaboration	178	0.54
91	Decade	66	0.53
92	Observation	138	0.50
93	Feasibility	80	0.49
94	Formation	149	0.48
95	Sdgs	65	0.48
96	Science	485	0.48
97	Experience	292	0.48
98	System	1154	0.46
99	Mechanism	315	0.43
100	Art	159	0.43

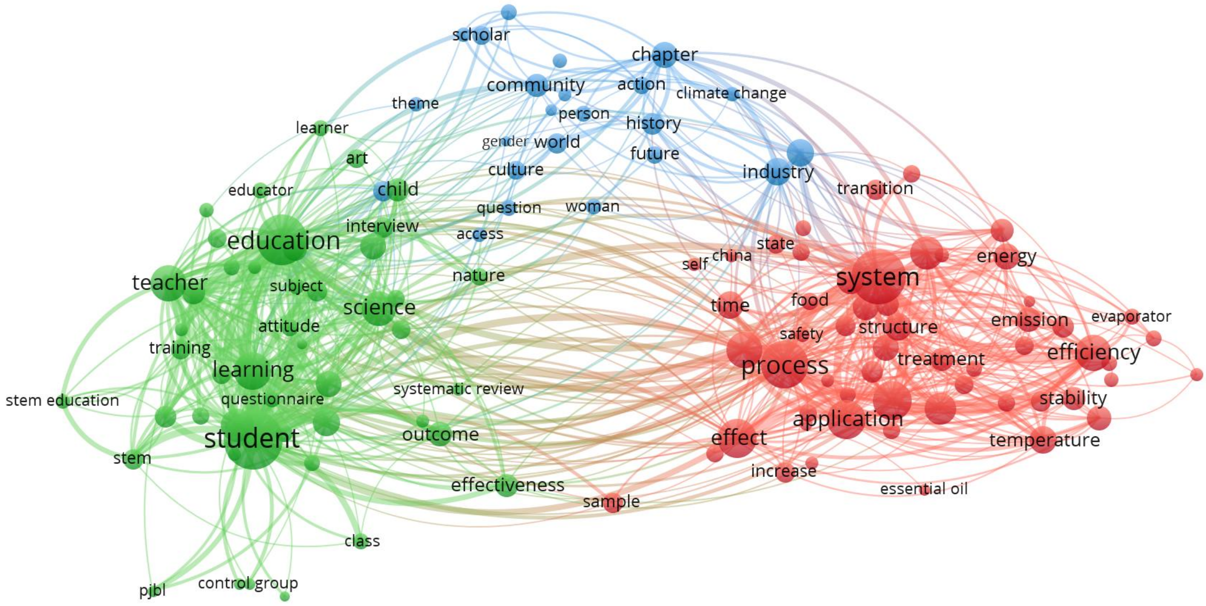

Figure 4. Network visualization

Table 2 and Figure 4 jointly show that the conceptual structure of STEAM research in science education contains both education-related themes and cross-domain terms. The most frequently occurring terms are dominated by broad educational keywords such as *student*, *education*, *learning*, *teacher*, and *science*. In Figure 4, these terms are grouped mainly within the green cluster, indicating the pedagogical, learner-centered, and instructional orientation of STEAM research in science education. This cluster reflects the central focus of the field, particularly in relation to classroom learning, teacher roles, student engagement, curriculum implementation, and science learning practices.

However, Figure 4 also reveals a red cluster consisting of terms such as *system*, *process*, *application*, *effect*, *efficiency*, and *energy*. Some of these terms may represent broader interdisciplinary or implementation-related discussions, but the presence of more technical terms such as *evaporator*, *emission*, and *essential oil* indicates residual database noise. This likely occurred because the term "STEAM" was also captured in non-educational contexts, particularly those related to steam as a technical concept in energy, engineering, or chemical production. Therefore, these technical terms were not interpreted as core themes of STEAM research in science education. Instead, the interpretation focused primarily on education-related terms and clusters.

The combined use of term frequency, relevance score, and network structure is therefore important for distinguishing central educational themes from peripheral or cross-domain terms in the mapped literature. In this study, Table 2 is retained to transparently report the results of the initial VOSviewer term extraction, while Figure 4 is used to show how relevant educational terms and residual cross-domain terms are positioned within the overall network. This interpretation helps clarify that the core conceptual structure of STEAM research in science education remains centered on students, teachers, learning, education, science, and instructional practices, while several technical terms are treated as peripheral noise rather than as dominant research themes.

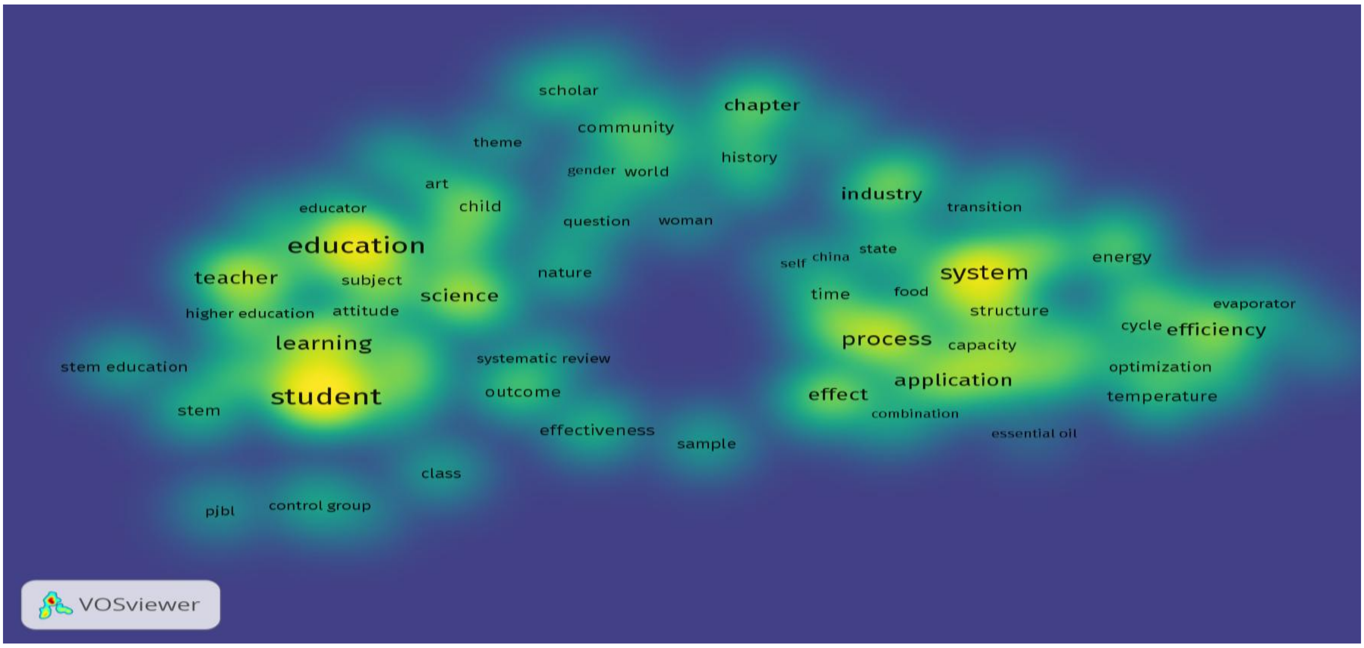

Figure 5. Density Visualisation

Figure 5 further strengthens the interpretation of Table 2 and Figure 4 by showing the density of the most influential terms in the mapped literature. The brightest zones are concentrated around student, education, and learning on the left side, and around system, process, application, and efficiency on the right side, indicating that these terms function as the main conceptual hotspots in the dataset. This density pattern confirms that STEAM research in science education is organized around two major orientations: a pedagogical cluster focused on learners, teaching, and educational contexts, and an applied cluster related to systems, processes, and implementation issues. Meanwhile, lower-density terms such as pjbl, higher education, climate change, industry, and energy appear as more specific or emerging topics that support, rather than dominate, the overall structure of the field. In bibliometric mapping, density visualization is useful for identifying the most intensively connected concepts and for highlighting which themes occupy the strongest positions within the intellectual landscape of a research domain (Aria & Cuccurullo, 2017; Cobo et al., 2011).

Table 3. Synthesis of Scopus-Indexed Articles

No.	Authors	Article Title	General Findings	Research Gap
1	English (2016)	STEM education K-12: Perspectives on integration	Argues that integrated STEM should connect disciplinary knowledge with authentic problem solving across K–12 contexts.	Provides a conceptual perspective but does not specifically map STEAM trends in science education or combine bibliometric and SLR approaches.
2	Kelley and Knowles (2016)	A conceptual framework for integrated STEM education	Proposes a widely used framework linking disciplinary integration, design, and real-world problem solving.	The study is conceptual and does not examine how STEAM themes evolve empirically across the science education literature.
3	Estapa and Tank (2017)	Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge	Shows that design-challenge-based professional development can support elementary teachers in implementing integrated STEM learning.	Focuses on teacher support at classroom level and leaves open the broader bibliometric structure of STEAM studies in science education.
4	Thibaut et al. (2018)	Integrated STEM education: A systematic review of instructional practices in secondary education	Identifies major instructional practices in secondary integrated STEM, including problem-based, inquiry-based, and design-oriented learning.	Concentrates on secondary STEM instruction and does not specifically synthesize STEAM trends across science education between 2016 and 2025.
5	Sarican and Akgunduz (2018)	The impact of integrated STEM education on academic achievement, reflective thinking skills towards problem solving and permanence in learning in science education	Reports positive effects of integrated STEM on achievement, reflective thinking, and retention in science learning.	The study demonstrates effectiveness in one context, but does not explain larger thematic developments in STEAM research.
6	Wandari et al. (2018)	The effect of STEAM-based learning on students' concept mastery and creativity in learning light and optics	Finds that STEAM-based learning improves concept mastery and creativity in a science topic.	The scope is topic-specific, so broader conceptual and publication trends in STEAM science education remain underexplored.
7	English and King (2019)	STEM integration in sixth grade: Designing and constructing paper bridges	Demonstrates how integrated STEM can foster design thinking and interdisciplinary learning in middle-grade contexts.	The article offers a classroom example, but it does not map the wider research landscape of STEAM in science education.
8	Margot and Kettler (2019)	Teachers' perception of STEM integration and education: A systematic literature review	Shows that teacher perceptions are central to successful STEM implementation and that integration is understood in varied ways.	The review centers on teacher perceptions and STEM, leaving STEAM-specific developments in science education insufficiently synthesized.
9	Martín-Páez et al. (2019)	What are we talking about when we talk about STEM education? A review of literature	Clarifies conceptual ambiguity in STEM education and highlights multiple ways the field is interpreted in the literature.	Focuses on STEM conceptions broadly and does not specifically analyze STEAM science education using bibliometric evidence.
10	Perignat and Katz-Buonincontro (2019)	STEAM in practice and research: An integrative literature review	Shows that STEAM has grown around creativity, interdisciplinarity, and design-based learning.	As an integrative review, it does not provide a focused bibliometric mapping of

No.	Authors	Article Title	General Findings	Research Gap
				STEAM in science education over a defined decade.
11	Rahmawati et al. (2019)	Developing critical and creative thinking skills through STEAM integration in chemistry learning	Demonstrates that STEAM integration in chemistry can support students' critical and creative thinking.	The study is context-specific and does not address cross-topic or cross-country patterns in science education research.
12	Rahmawati et al. (2020)	Developing students' critical thinking: A STEAM project for chemistry learning	Finds that project-based STEAM activities in chemistry contribute to critical thinking development.	The article focuses on intervention outcomes and does not identify broader publication, collaboration, or keyword trends.
13	Adriyawati et al. (2020)	STEAM-project-based learning integration to improve elementary school students' scientific literacy on alternative energy learning	Reports that STEAM-PjBL can improve scientific literacy in elementary science contexts.	The focus is limited to a specific literacy outcome and does not synthesize the wider evolution of STEAM research.
14	Li et al. (2020)	Research and trends in STEM education: A systematic review of journal publications	Maps broad STEM education trends and shows rapid growth of the field in journal publications.	It addresses STEM at a general level and does not specifically concentrate on STEAM in science education.
15	Marín-Marín et al. (2021)	STEAM in education: A bibliometric analysis of performance and co-words in Web of Science	Reveals productivity patterns and keyword structures in STEAM research using bibliometric methods.	The analysis is broad and database-specific, leaving room for a focused Dimensions-based review in science education.
16	Lo (2021)	Design principles for effective teacher professional development in integrated STEM education: A systematic review	Identifies key principles of teacher professional development for integrated STEM implementation.	The review addresses professional development, but does not map the conceptual structure of STEAM science education research.
17	Boice et al. (2021)	Supporting teachers on their STEAM journey: A collaborative STEAM teacher training program	Shows that collaborative training programs can improve teachers' readiness to implement STEAM.	The study centers on one training model and does not examine broader research trajectories across the field.
18	Anggraeni and Suratno (2021)	The analysis of the development of the 5E-STEAM learning model to improve critical thinking skills in natural science lesson	Presents a 5E-STEAM model that supports critical thinking in science learning.	The study is model-development oriented and does not provide macro-level evidence about STEAM publication patterns.
19	Li et al. (2022)	A systematic review of high impact empirical studies in STEM education	Synthesizes characteristics of influential empirical STEM studies and highlights dominant methodological patterns.	The focus is on high-impact STEM studies rather than STEAM-specific developments in science education.
20	Lupión-Cobos et al. (2022)	Building STEM inquiry-based teaching proposal through collaborations between schools and research centres: Students' and teachers' perceptions	Shows that inquiry-based collaboration between schools and research centers supports STEM learning and positive perceptions.	It explores one collaborative teaching context but does not capture broader thematic and bibliometric developments.
21	Breda et al. (2023)	Teachers' perceptions of STEAM education	Highlights that teachers value STEAM but still face conceptual and implementation challenges.	The study emphasizes perceptions and practice, yet leaves global publication and keyword structures insufficiently examined.
22	Filipe et al. (2024)	Integrated STEAM education for students' creativity development	Shows that integrated STEAM education contributes to the	The study focuses on one core outcome and does not map how creativity relates

No.	Authors	Article Title	General Findings	Research Gap
			development of student creativity.	to other dominant STEAM themes in science education.
23	Portillo-Blanco et al. (2024)	A systematic literature review of integrated STEM education: Uncovering consensus and diversity in principles and characteristics	Identifies common principles and diversity in integrated STEM education across studies.	Although comprehensive, it is centered on integrated STEM broadly and does not specifically target STEAM science education.
24	Suryanti et al. (2024)	STEAM-project-based learning: A catalyst for elementary school students' scientific literacy skills	Finds that STEAM-PjBL can strengthen scientific literacy in elementary learners.	The study is outcome-oriented and limited to one level of education, leaving wider trend analysis open.
25	Yim et al. (2025)	STEAM in practice and research in primary schools: A systematic literature review	Shows that primary-school STEAM research is growing, with creativity and interdisciplinary practice as major themes.	The review is restricted to primary schools and does not provide a wider science education bibliometric mapping.
26	Amanova et al. (2025)	A systematic review of the implementation of STEAM education in schools	Summarizes implementation patterns of STEAM across school contexts and identifies recurrent challenges.	The scope is school implementation in general and does not specifically analyze science education as a distinct domain.
27	Spyropoulou et al. (2025)	We Believe in STEAM Education, but We Need Support: In-service teachers' voices on the realities of STEAM implementation	Shows that teachers support STEAM conceptually but need practical, structural, and professional support.	The study focuses on teacher voices and does not address macro-level knowledge structures or publication trends.
28	Rahman et al. (2025)	Augmented reality in STEAM education: A systematic review of collaborative practices for primary schools	Indicates that augmented reality can enrich collaborative STEAM practices, especially in primary education.	The review emphasizes digital intervention and primary contexts, leaving the broader science education landscape underexplored.
29	An (2020)	The impact of STEAM integration on preservice teachers' disposition and knowledge	Finds that STEAM integration positively affects preservice teachers' knowledge and dispositions.	The focus is on teacher preparation, not on mapping research trends or conceptual clusters in science education.
30	Rahmawati et al. (2024)	Developing students' chemical literacy through the integration of dilemma stories into a STEAM project on petroleum topic	Shows that integrating dilemma stories into STEAM projects can strengthen students' chemical literacy.	The study is topic-specific and does not explain how chemical-literacy research fits within broader STEAM science education trends.

The review of the 30 articles indicates that research on *STEAM Research in Science Education* has evolved from a phase of conceptualization to empirical implementation, and subsequently to synthesis and mapping. In the early stage, studies primarily focused on defining and positioning STEM/STEAM as an integrative approach in education. This is evident in conceptual works such as English (2016) and Kelley and Knowles (2016), which emphasized the importance of disciplinary integration in connecting learning with real-world problems. Subsequently, Martín-Páez et al. (2019) showed that debates on STEM education concern not only content but also meaning, boundaries, and forms of integration. In a more specific context, Perignat and Katz-Buonincontro (2019) argued that STEAM developed by incorporating the *arts* to strengthen creativity, design, and expression. This development was further expanded by bibliometric studies such as Li et al. (2020) and Marín-Marín et al. (2021), as well as more recent synthesis studies such as Portillo-Blanco et al. (2024), all of which show that the field has grown rapidly while still displaying conceptual diversity and varying research directions.

From the perspective of substantive focus, the articles in the table show that STEAM in science education is strongly associated with twenty-first-century skills, particularly critical thinking, creativity, scientific literacy, and problem solving. Sarican and Akgunduz (2018) demonstrated that integrated STEM has positive effects on academic achievement, reflective thinking, and learning retention. Similar findings were reported by Wandari et al. (2018), who found improvements in conceptual understanding and creativity, as well as by Rahmawati et al. (2019) and Rahmawati et al. (2020), who emphasized the role of STEAM in developing critical and creative thinking in chemistry learning contexts. At the literacy level, Adriyawati et al. (2020) and Suryanti et al. (2024) showed that *STEAM-project-based learning* is effective in strengthening students' scientific literacy. Meanwhile, Rahmawati et al. (2024) extended this line of inquiry by showing that STEAM can also be combined with dilemma stories to develop chemical literacy. These empirical findings therefore demonstrate that STEAM is not only relevant as an integrative approach, but also as a pedagogical strategy with strong potential to enhance cognitive achievement and higher-order thinking skills in science education.

Beyond student learning outcomes, the studies in the table also indicate that teachers and implementation support are decisive factors in the success of STEAM. Margot and Kettler (2019) emphasized that teachers' perceptions of STEM integration remain highly diverse in terms of meaning, depth of integration, and implementation strategies. Estapa and Tank (2017) showed that the implementation of integrated STEM requires structured professional development, while Lo (2021) argued that teacher professional development is a key prerequisite for successful STEM/STEAM implementation. In a more applied context, Boice et al. (2021) demonstrated that collaborative training programs can strengthen teachers' readiness to implement STEAM instruction. These findings are reinforced by Breda et al. (2023), Amanova et al. (2025), and Spyropoulou et al. (2025), all of whom consistently show that teachers generally hold positive attitudes toward STEAM, but still face conceptual, pedagogical, and structural challenges. Thus, one of the major patterns emerging from the SLR table is that STEAM is not merely a matter of instructional design; it also depends on teacher readiness, institutional support, and implementation capacity in schools.

The articles in the table further reveal that STEAM research in science education spans multiple educational levels and contexts, ranging from elementary school and secondary school to teacher education and higher education. English and King (2019) showed how STEM integration can be implemented in middle-grade contexts through simple construction-based design tasks, while Lupión-Cobos et al. (2022) highlighted the importance of collaboration between schools and research centers in strengthening inquiry-based STEM learning. At the elementary school level, Yim et al. (2025) found that STEAM research has grown substantially, with strong emphasis on creativity and interdisciplinarity. On the other hand, An (2020) shifted the focus toward *preservice teachers* and found that STEAM integration contributes to their knowledge and dispositions. Rahman et al. (2025) further showed that technologies such as *augmented reality* are beginning to be integrated into STEAM practices, particularly in collaborative elementary-school contexts. This suggests that STEAM is not confined to a single educational level but rather represents a research domain that continues to expand across educational stages and innovation contexts.

Nevertheless, the SLR table also reveals a considerable degree of fragmentation in STEAM research within science education. Most studies still focus on limited contexts, specific topics, or single outcome variables, such as creativity (Filipe et al., 2024), scientific literacy (Adriyawati et al., 2020; Suryanti et al., 2024), critical thinking (Rahmawati et al., 2019, 2020; Anggraeni & Suratno, 2021), or chemical literacy (Rahmawati et al., 2024). At the same time, the review and bibliometric articles that already exist still tend to address STEM or STEAM in broad terms, such as Li et al. (2020), Li et al. (2022), Marín-Marín et al. (2021), and Portillo-Blanco et al. (2024), without specifically focusing on STEAM in science education as a distinct domain. Even when the focus becomes narrower, discussion is often limited to certain educational levels, such as elementary school (Yim et al., 2025), or to specific aspects of implementation, such as teacher training (Boice et al., 2021) and implementation support (Spyropoulou et al., 2025). In other words, the field has grown, but its conceptual map and developmental direction within science education have not yet been fully articulated.

Based on the overall findings presented in the table, it can be understood that the major research gap lies in the absence of a synthesis that truly integrates publication trends, thematic structure, methodological orientation, and substantive content of STEAM specifically within the context of science education. Empirical studies have demonstrated the potential of STEAM for various learning outcomes, while review studies have highlighted the diversity of definitions, implementation models, and practical challenges. However, there remains a need for research that bridges these strands through the combined use of bibliometric analysis and systematic literature review. In this sense, the present study is important because it not only identifies what has been studied, but also shows how the field has developed, which themes are dominant, which contexts are most frequently investigated, which approaches are most used, and where the remaining research gaps lie. From this perspective, the study contributes to clarifying the knowledge structure of STEAM in science education while also strengthening the foundation for future research agendas.

Although the literature on STEAM in science education has expanded rapidly, the bibliometric mapping and density visualization in this study indicate that the integration of STEAM with culture, indigenous knowledge, and ethnoscience has not yet become a mainstream line of inquiry. This is reflected in the relatively peripheral position of terms such as culture (relevance 0.60), community (0.57), sustainable development goal (0.48), and art (0.43), which appear in low-density areas and do not occupy the central network positions held by dominant terms such as student, education, learning, system, process, and application. Moreover, the absence of terms explicitly representing indigenous knowledge, local wisdom, ethnoscience, or culturally responsive teaching among the high-frequency and high-relevance keywords suggests that the connection between STEAM and local cultural contexts remains peripheral within the indexed research landscape. This finding is consistent with earlier studies showing that STEAM research has largely focused on disciplinary integration, creativity, scientific literacy, and general pedagogical implementation, while giving limited attention to culture and local knowledge as epistemic foundations of learning (Perignat & Katz-Buonincontro, 2019; Portillo-Blanco et al., 2024; Yim et al., 2025).

At the same time, several recent studies demonstrate that approaches integrating cultural responsiveness, socio-scientific issues, and ethnoscience reconstruction hold strong potential for enriching science learning. Arifin et al. (2024a) showed that learning tools based on the culturally responsive transformative teaching model with a socio-scientific issues approach had good validity and practicality, while Ahmad et al. (2024) extended this line of work through the development of an ecosystem e-module integrating cultural dimensions, socio-scientific issues, and digital technology. More specifically, Arifin, et al. (2024b) demonstrated that the Pedak Api tradition of the Narmada community can be reconstructed as a source of ethnoscience for biology learning, and Arifin, et al. (2025) further confirmed the validity of learning tools grounded in culturally responsive transformative teaching. However, these studies remain largely contextual and local in scope, and they have not yet been explicitly positioned within the broader framework of STEAM. Therefore, an important research gap lies in the limited number of studies that systematically integrate STEAM with culture and indigenous knowledge, while also examining how such an approach can function as a science learning model that is not only creative and interdisciplinary, but also contextual, rooted in local wisdom, and relevant to students' socio-cultural identities.

Conclusion

This study shows that STEAM research in science education has developed significantly during the 2016–2025 period, both in terms of publication growth and thematic diversity. The bibliometric analysis reveals that STEAM studies are still dominated by general themes such as *student*, *education*, *learning*, and *science*, while the integration of STEAM with culture, indigenous knowledge, and ethnoscience remains peripheral. The SLR findings further confirm that STEAM research in science education has mainly focused on twenty-first-century skills, scientific literacy, creativity, and teacher implementation support, but remains fragmented across contexts, educational levels, and outcome variables.

This study contributes to mapping the intellectual structure of STEAM research in science education by integrating macro-level bibliometric analysis and micro-level systematic literature review. Through this integrated approach, the study provides a clearer understanding of publication trends, dominant themes, thematic relationships, methodological tendencies, and emerging research gaps in the field. Therefore, future research should move beyond general STEAM implementation and strengthen the integration of STEAM with local knowledge systems, including indigenous knowledge, ethnoscience, and culturally situated learning practices. Such integration is important to develop STEAM learning that is more contextual, culturally responsive, and meaningful for science education.

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