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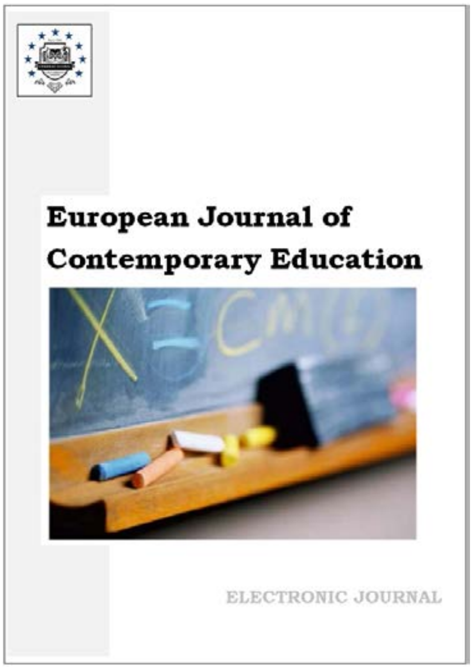

Bibliometric Analysis of STEAM Education and Technical Thinking in Primary Schools: Trends and Prospects (2014–2025)

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Abstract

Relevance: The integration of Science, Technology, Engineering, Art, Mathematics (STEAM) education in primary schools aims to foster students' technical thinking and creativity, and establish foundations for success in technology fields. A bibliometric analysis of Scopus research shows a growing interest in STEAM education in primary schools, identifying trends and key authors.

Method: This study presents a bibliometric analysis of 1364 scientific publications on STEAM education, primary education, and technical thinking development based on Scopus data from 2014 to 2025. The focus was on how STEAM approaches are integrated into primary education to promote critical and technical thinking.

Results: Since 2018, publication activities have increased, indicating growing global interest in interdisciplinary learning models.

Conclusions: Most studies were conducted in developed countries including the United States, South Korea, China, and Spain. Four main thematic clusters emerged: STEAM curriculum integration, cognitive and problem-solving skills development, digital tools and robotics use, and teacher training.

Keywords: bibliometric analysis, elementary school, Scopus, STEAM, technical thinking.

1. Introduction

The integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) into primary education is recognized as a promising approach for fostering technical thinking in young learners (Bertrand, Namukasa, 2020; Asunda et al., 2023). This interdisciplinary paradigm focuses on cultivating creativity, problem-solving abilities, and critical thinking through project-based activities (Mutawah et al., 2021; Rahmawati et al., 2019). Given the rapid technological

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advancement across all spheres of life, developing these competencies from an early age becomes critically important for preparing students for the future. Technical thinking enables pupils not only to navigate the technological world but also to actively shape it, understand the principles underlying technologies, and apply them to address relevant challenges (Lytra, Drigas, 2021; Ayanwale et al., 2024). It provides a structured approach to solving complex problems, develops analytical capabilities (Kurnia, Caswita, 2020), serves as a catalyst for creativity and innovation (Mamaeva et al., 2020), and establishes a foundation for adaptability and lifelong learning amidst constant technological change (Fleer, 2020). Furthermore, cultivating technical thinking in primary school students represents a strategic response to the global shortage of qualified professionals in technical fields (Marín et al., 2021; Reinhardt, 2024).

However, the successful integration of STEAM education in primary schools faces significant challenges, primarily related to teacher preparedness and technological accessibility issues. Many primary school educators lack specialized training in interdisciplinary STEM/STEAM methodologies, which is crucial for effective implementation (Afizal Abd Ghani et al., 2023; Agudelo Rodríguez et al., 2024). Professional development programs often remain fragmented and fail to equip teachers with the necessary pedagogical content knowledge and confidence to lead project-based STEAM activities (Huang et al., 2022; Fabian et al., 2024).

Simultaneously, equitable access to digital tools and resources remains a critical issue. Disparities in technological infrastructure between regions and schools can exacerbate existing educational inequalities, hindering the adoption of hands-on, technology-enhanced learning, which is central to STEAM (UNESCO, 2023; OECD, 2023). The effectiveness of interventions such as Bring Your Own Device (BYOD) policies also depends heavily on supportive school environments and teacher readiness to integrate personal technology into the curriculum (McLean, 2016; Schmitz et al., 2024).

These intertwined challenges of teacher competency and digital equity represent a significant gap between the theoretical potential of STEAM education and its practical application in diverse primary school contexts in Malaysia. Therefore, a systematic analysis of existing research trends is needed to map the current knowledge landscape, identify effective strategies for teacher support, and highlight directions for overcoming the technological barriers. This bibliometric review aims to address this need by examining publication trends, key themes, and research fronts in STEAM education and technical thinking development from 2014 to 2025.

2. Literature review and problem statement

Research confirms the effectiveness of contemporary pedagogical tools for developing essential skills. Specifically, the use of 2D and 3D didactic games has proven effective in enhancing spatial reasoning and components of STEAM thinking among students. Incorporating such games into the educational process facilitates the integration of interdisciplinary knowledge, fostering logic, creativity, and visualization skills (Totikova et al., 2020; Pytlík, Kostolányová, 2019). Educational games stimulate student interest and engagement, positively impacting motivation and academic outcomes (Durak, Yılmaz, 2019). While 2D games (e.g., puzzles, graphic builders) develop fundamental understanding of geometric shapes and proportions, 3D games enable students to interact with objects in three-dimensional space, significantly improving mental rotation and design capabilities (Forbes, 2020; Totikova et al., 2019).

The pedagogical potential of STEAM lies in its interdisciplinarity: it enables the exploration of scientific concepts through the lens of technology and engineering, their interpretation through the arts, and grounding in mathematical logic (Sun, 2021; Sung et al., 2023; Long, 2017). This approach promotes the development of STEM literacy, problem-solving skills, collaboration, and critical thinking (Rice, 2020; Okwara, Pretorius, 2023), alongside understanding STEM concepts, creativity (Bui et al., 2022; Antwi et al., 2022), and computational thinking as a fundamental skill for the digital era (Bedar, 2020). The integration of digital tools (augmented reality, platforms like Smart cars) and innovative technologies opens new avenues for immersive and project-based learning within STEAM (Rahmawati et al., 2021; Li et al., 2020), enhances digital literacy (Lu, 2020; Piila et al., 2020), and necessitates corresponding teacher preparation (Handayani, 2020; Liu, Shi, 2019; Le et al., 2021).

Bibliometrics serves as an effective tool for systematizing the growing body of research in STEAM education. Bibliometric analysis, understood as a quantitative method for assessing the research landscape, allows for the identification of trends, key authors, influential publications, citation networks, and the intellectual structure of the field (Lytra, Drigas, 2021). Such studies are particularly valuable for understanding the state of the art, priorities, methodological approaches, and geographical distribution of work in dynamically evolving interdisciplinary areas like STEAM in primary education focused on technical thinking development (Bedar, 2020: 84). Despite increasing interest in STEAM and technical thinking (Phuong et al., 2023), there remains a need for a systematic bibliometric study specifically focusing on the convergence of three key elements: STEAM education, primary school, and technical thinking development. Existing bibliometric works on STEM/STEAM (Supriyadi et al., 2025; Ekawati et al., 2025; Ha et al., 2020) do not address this specific yet significant niche. Identifying the most productive research directions, influential works, and crucially, existing gaps specifically within the context of developing technical thinking in primary school students through STEAM remains a pertinent task.

Research aim and objectives

In light of the above, the aim of this study is to conduct a comprehensive bibliometric analysis of scientific publications indexed in the Scopus database from 2014 to 2024, to identify trends, structure, and future research directions in the application of the STEAM approach in primary education for developing technical thinking.

To achieve this aim, the following objectives are addressed:

1. Identify key elements of the research landscape: determine the most influential publications, authors, scientific journals, institutions, and countries contributing significantly to this field.

2. Analyze the conceptual structure of the field: identify main topics, trends, and their developmental dynamics through the analysis of keywords, thematic clusters, and the evolution of research interests.

3. Assess scientific impact and collaboration: analyze citation networks to evaluate the impact of key publications and map collaboration networks between authors, institutions, and countries.

4. Identify gaps and promising directions: based on the identified trends and field structure, delineate under-researched aspects and formulate recommendations for future research.

5. Synthesize findings for educational practice: summarize the analysis results to provide evidence-based recommendations for designing and enhancing STEAM curricula, pedagogical strategies, and activities that effectively develop technical thinking in primary school students.

The conducted analysis aims to provide a deep understanding of the current state of research, serve as a foundation for further inquiry, and contribute to the development of more effective educational practices and policies in STEAM education at the primary level (Saputra, 2025).

3. Methodology

The Scopus database was selected as the source of bibliographic data – a leading bibliographic platform covering a wide spectrum of peer-reviewed scientific publications in education, including research related to the STEAM approach (Alreahi, 2023).

Only peer-reviewed journal articles, conference proceedings, and book chapters were included; non-peer-reviewed sources such as editorials, opinion pieces, and dissertations were excluded to maintain research integrity. Following the initial search, a multi-stage screening process was applied. Records were imported into reference management software for deduplication and organization.

Bibliometric methods enable detailed analysis of publication trends, document types, and language distribution. VOSviewer software was employed to identify thematic clusters and conceptual relationships through keyword co-occurrence analysis (Verma, 2020). Similarity viewer tools facilitate the visualization of bibliographic linkages between sources and countries (Modak, 2020). Extracted data included titles, abstracts, authors, affiliations, publication years, keywords, and citation counts (Shatu et al., 2022).

Research scope and analytical objectives

This study aims to systematize and visualize the scientific discourse concerning STEAM education, technical thinking, and primary schooling. Its primary objective is to identify leading authors, institutions, countries, dominant research topics, and the dynamics and structure of publication activity within this domain from 2014 to 2025.

The publication filtering and selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, ensuring reproducibility, transparency, and analytical consistency (Page et al., 2021; Parums, 2021).

Data source

Scopus was chosen as the primary bibliographic database due to its extensive coverage of peer-reviewed scientific journals worldwide and its provision of reliable data for bibliometric studies (Figure 1).

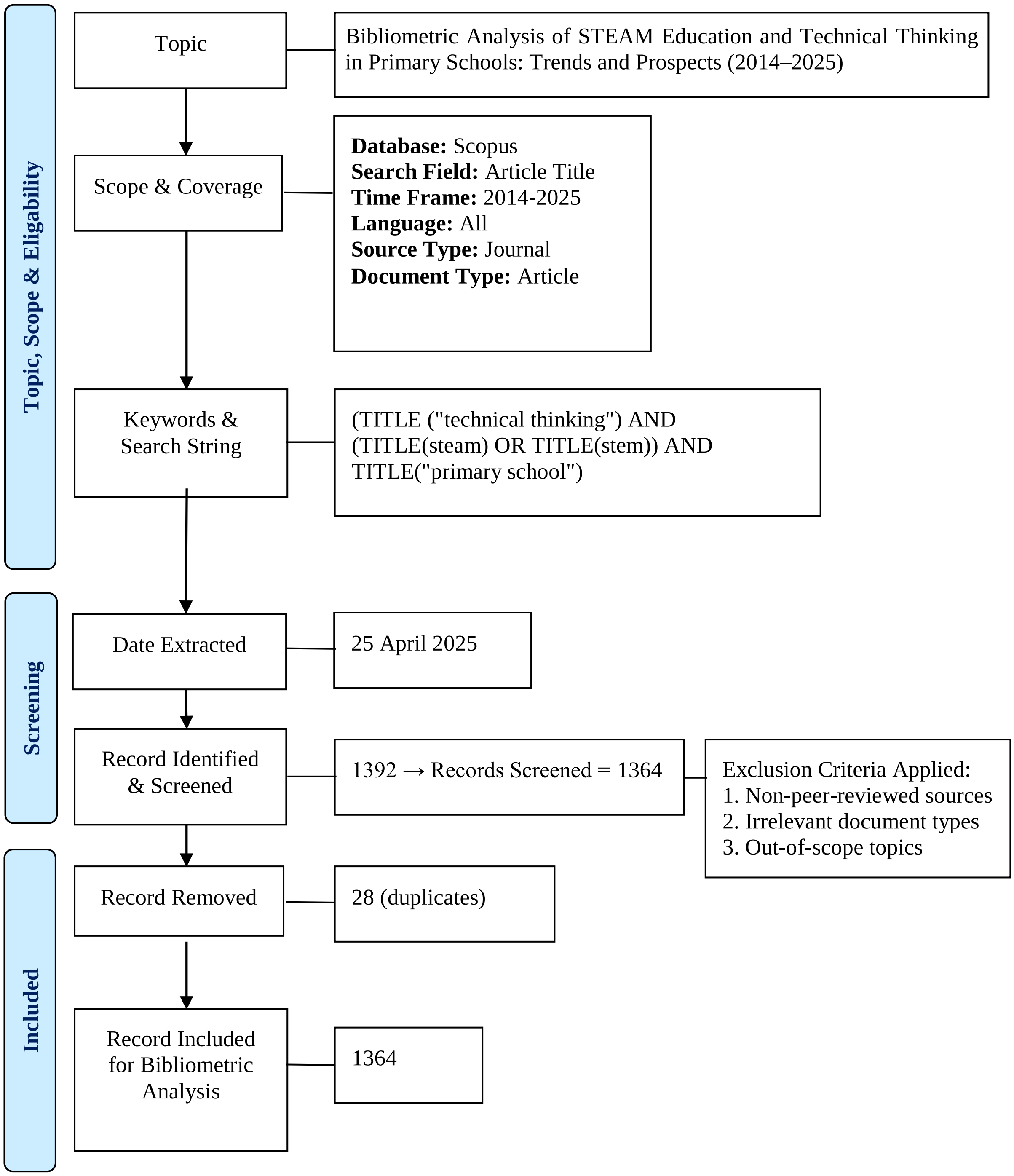

Fig. 1. PRISMA Flowchart of the Search Strategy

Search criteria

The search strategy was designed to maximize the coverage of relevant publications while maintaining precision. The query was constructed using Boolean operators (AND, OR) and truncation (*) to account for plural forms and common suffixes of the words.

The initial search string was refined through multiple pilot searches to balance the recall and relevance. The final query searched for terms in the article title, abstract, and keyword fields. To address the reviewer's concern regarding synonyms, the search incorporated alternative terms for the key concepts.

"Primary school" was expanded to include its common synonym "elementary school".

"Technical thinking" was expanded to include the related term "engineering thinking".

The acronyms "STEAM" and "STEM" were searched as they are standardized terms in the literature.

No subject area filters were applied to the database to ensure a comprehensive search across all potential disciplines, including social sciences, engineering, computer science, and education.

The final search string used in the Scopus database is as follows:

(TITLE-ABS-KEY ("technical thinking" OR "engineering thinking") AND TITLE-ABS-KEY (steam OR stem) AND TITLE-ABS-KEY ("primary school" OR "elementary school"))

Search parameters:

1. **Database:** Scopus
2. **Search Field:** Title, Abstract, Keywords
3. **Time Frame:** 2014-2025
4. **Document Type:** Article or Review
5. **Source Type:** Journal
6. **Language:** All
7. **Subject Area:** No filters applied

The database search was conducted in April 2025. After filtering for document type and removal of duplicates, 1364 unique publications were identified for inclusion in the subsequent analysis.

Data Analysis Methods

The following bibliometric tools and methods were employed:

– **Publication Trend Analysis:** Reflecting the quantitative dynamics of publications by year.

– **Author and Affiliation Analysis:** Identifying the most prolific researchers, institutions, and countries.

– **Source Analysis:** Determining the most cited scientific journals.

– **Co-authorship and Citation Analysis:** Conducted using VOSviewer and Bibliometrix (R package).

– **Keyword Analysis:** Reconstructing the conceptual structure of the research field.

– **Data Visualization:** Generating science maps, cluster models, and thematic networks using VOSviewer and SciMAT.

– Data extracted from Scopus included publication titles, abstracts, authors, affiliations, publication years, keywords, and citation counts (Shatu et al., 2022).

Limitations

The analysis covers only publications indexed in the Scopus database and does not include other databases such as Web of Science or ERIC.

SciMAT was used to analyze data pertaining to the dynamic and structural longitudinal development of the entire literature corpus.

A longitudinal analysis was conducted across three time periods: P1 (2014–2017), P2 (2018–2021), and P3 (2022–2025). This periodization was not arbitrary but was justified through a combined qualitative and quantitative approach.

Quantitative Justification: An analysis of the annual publication growth rate revealed distinct phases of activity in the field. The transition from P1 to P2 (2017–2018) coincided with a significant acceleration in the number of publications, marking the field's move from an emergent to a growth phase. The end of P2 (2021) was selected because it preceded the observed diversification of research topics and methodologies in P3, which aligned with a new, even steeper growth trajectory.

Qualitative Justification: The periods correspond to major contextual shifts in global education.

P1 (2014–2017): The formative years, when research focused on establishing the foundational principles of STEAM in primary education.

P2 (2018–2021): A period of institutionalization and rapid growth, heavily influenced by the global push for digital skills and the immediate impact of the COVID-19 pandemic, which accelerated the adoption of educational technology.

P3 (2022–2025): The current phase of maturation and diversification is characterized by the integration of advanced technologies (AI, AR/VR) and a stronger focus on sustainable and inclusive pedagogical models.

This division into four-year intervals effectively captures major evolutionary stages while providing a sufficient number of publications per period for a robust bibliometric analysis.

Keyword trend analysis revealed sustained growth in publications on the topics:

– "Educational Robotics" (average annual growth: +25 %)

– "Development of Technical Thinking" (+18 %)

– "Interdisciplinary Approaches" (+15 %).

– The most significant publication growth occurred between 2019 and 2023.

This includes examining the evolution of keywords grouped by theme across distinct, predefined time periods (Oliveira et al., 2019).

Term recognition and cluster construction were based on 263 keywords, of which 70 were identified as most significant.

Additionally, a semantic network was constructed to illustrate the logical relationships between core terms (Figure 2a). Node size corresponded to keyword frequency, color indicated cluster affiliation, and line thickness represented the strength of thematic association.

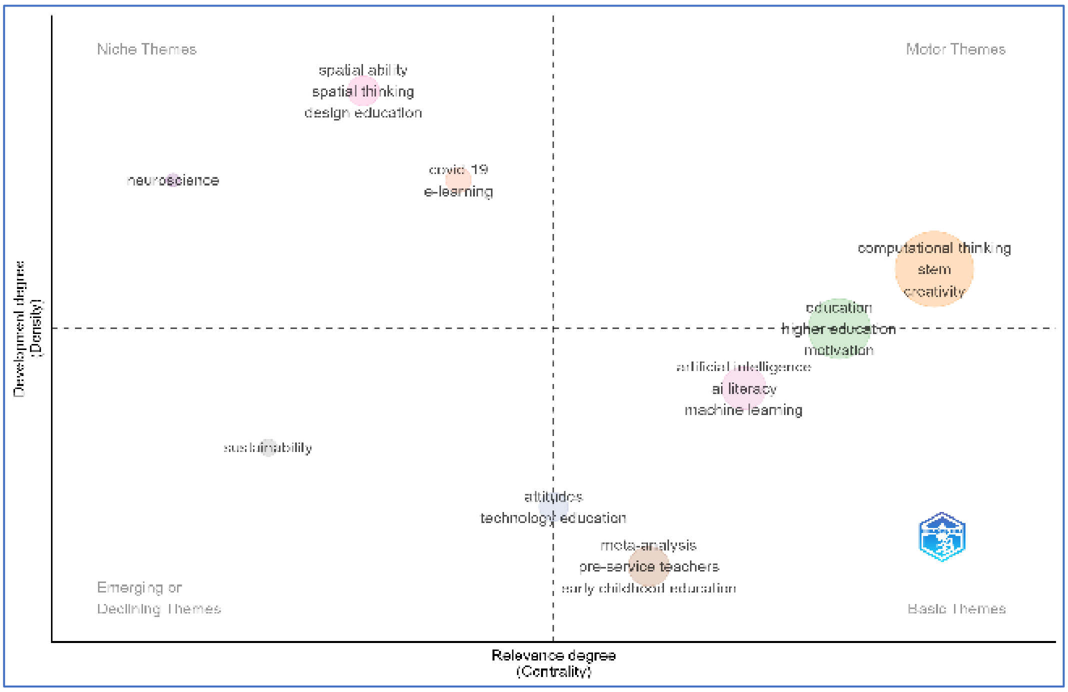

Fig. 2a. Strategic diagram of thematic clusters (based on density and centrality metrics indicators)

This matrix classifies research themes into four quadrants using two metrics:

1. Centrality (horizontal axis): Degree of connection with other knowledge domains.

2. Density (vertical axis): Level of internal theme development.

Thematic clusters were classified based on centrality (influence on other themes) and density (internal theme maturity), assigning them to one of four quadrants:

Q1 (Upper Right): Motor/Trending Themes (High centrality and density): "STEAM Pedagogy", "Project-Based Learning".

Q2 (Upper Left): Established/Niche Themes (High density, low centrality): "Assessment of Technical Thinking".

Q3 (Lower Left): Emerging/Declining Themes: "Augmented Reality in Primary Education".

Q4 (Lower Right): Fundamental/Cross-cutting Themes (High centrality, low density): "Interdisciplinary Approaches".

Circle size corresponds to publication volume per theme (Yan, Wang, 2023).

The visualization illustrates:

1. Nodes (circles): 70 key terms selected by occurrence threshold (minimum 5 mentions).

2. Node Size: Frequency of the term's appearance in publications (n = 263 keywords).

3. Cluster Colors: Thematic groups identified by the clustering algorithm.

4. Line Thickness: Strength of conceptual associations between terms.

Primary clusters (Figure 2b):
Red: Technical Thinking and Engineering Competencies.
Blue: Digital Tools in Education.
Green: STEAM Pedagogical Strategies.
Yellow: Cognitive Development of Primary School Students.

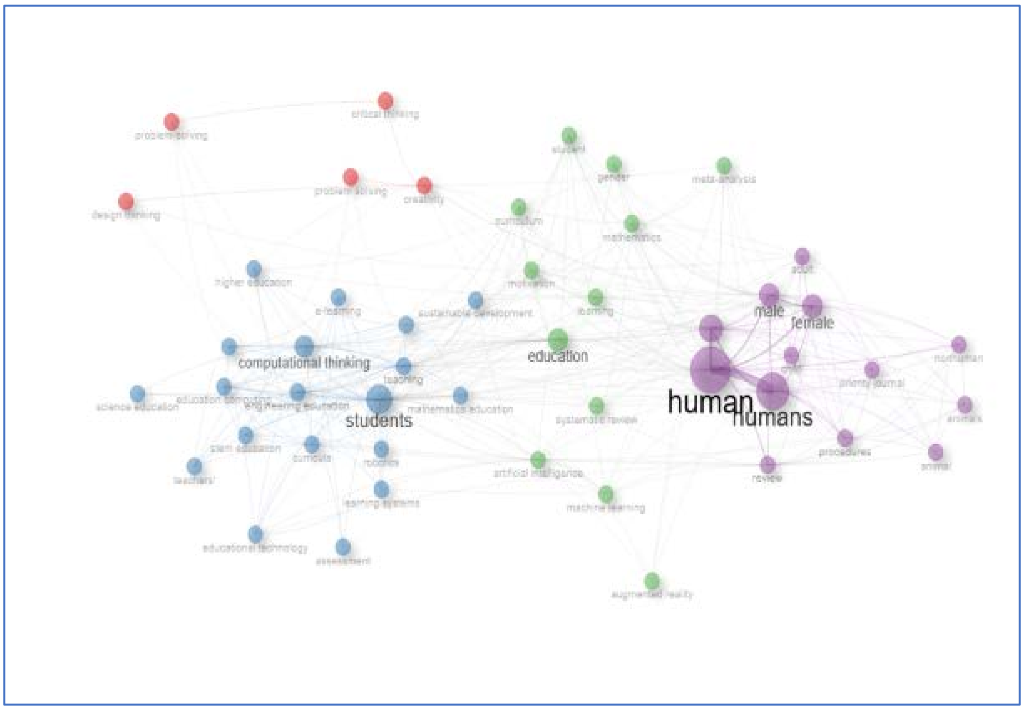

Fig. 2b. Semantic network of key terms relationships

Dynamic Discipline Development Model (Figure 2c)

This corresponds to the application of SciMAT for analyzing structural and temporal theme evolution (Ha et al., 2020). Results indicate a shift from isolated pedagogical studies towards comprehensive interdisciplinary models.

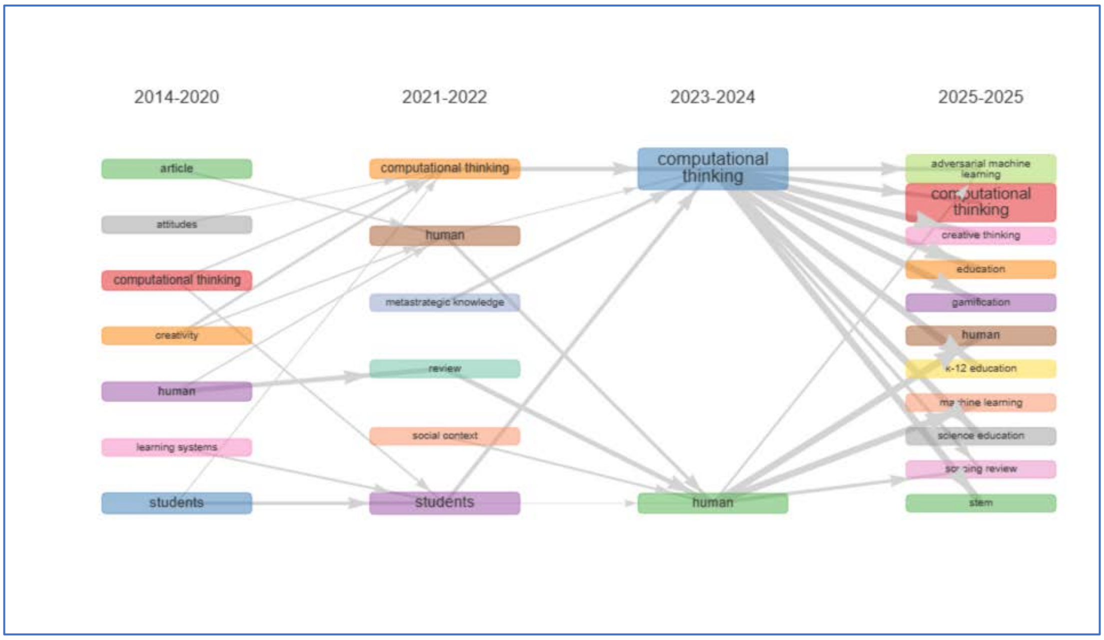

Fig. 2c. Thematic Evolution: Evolution of thematic areas across periods
(P1: 2014–2017, P2: 2018–2021, P3: 2022–2025).

The evolution map reflects thematic transformations across three periods:
P1 (2014–2017): Field Emergence
Dominant Themes: "Foundational STEM Education", "Basic Engineering Skills".
Growth Rate: +8.2 % annually.
P2 (2018–2021): Institutionalization
Emerging Themes: "Educational Robotics" (+25 % annually).
Stabilizing Themes: "Development of Technical Thinking" (+18 %).
P3 (2022–2025): Diversification
Trends: "AI in Primary Education", "STEAM Gamification".
Interdisciplinary Linkages: +34 %.
Legend:
Solid Lines: Direct thematic continuity.
Dashed Lines: Partial conceptual inheritance.
Line Thickness: Strength of thematic association.
Colors: Correspond to clusters in Figure 2b.

4. Results

In recent years, the concepts of Education, Science and Technology, Engineering, Arts, and Mathematics (STEAM) have become increasingly important in primary education. Particular attention is paid to the formation of technical thinking in primary school students as a fundamental cognitive competence that contributes to the development of a creative and logical approach to problem-solving. Against the backdrop of the active introduction of technology into the educational process, the relevance of research in this area has increased significantly. Bibliometric analysis allows quantification of the scale of academic interest and identification of key areas, centers of scientific activity, and dynamics of the development of STEAM approaches in the context of primary education.

The Scopus database was chosen for analysis *because of* its broad coverage, high level of representativeness, and strict indexing criteria to ensure the quality and relevance of scientific publications. This study covered publications from 2014 to 2025. The selection of materials was carried out according to the keywords "STEAM", "primary school" and "technic think," with restrictions on language (English) and type of documents (scientific articles, reviews, conference proceedings). The data was carried out using Microsoft Excel, and subsequent bibliometric analysis was carried out using VOSviewer, Bibliometrix (R-package) and the "Publish or Die" tools.

During the analysis, 1392 publications were identified for the period of 2014–2025. After removing duplicate publications (n = 28), 1364 publications were selected for bibliometric analysis.

The analysis presented in Table 1 covers 1,364 publications classified by source type. The leading position is occupied by articles–659 publications (48.3 %)–which indicates the steady dominance of journal publications in the academic landscape. This was followed by books (384, 28.2 %) and chapters (119, 8.7 %), which also occupied a significant share, especially in interdisciplinary fields and the humanities.

Reviews and conference proceedings were presented at 7.8 % and 7.0 %, respectively, confirming their importance as formats for systematizing and disseminating new scientific ideas. Less common forms of publication include editorials, notes, and a single retracted source, demonstrating differences in the academic culture of publications by field of expertise.

The results of the analysis confirmed the key role of scientific articles as the main format of communication in the academic environment, especially in the natural and applied sciences. However, the high proportion of books and chapters also highlights the importance of in-depth theoretical elaboration in the humanities and social sciences (Donthu et al., 2021).

This source allocation structure is consistent with previous research, showing the growing role of journals as the main channels for the dissemination of scientific knowledge. However, the growing number of books and peer-reviewed chapters point to the importance of alternative forms of knowledge representation, especially in the fundamental theoretical works of Marzi et al. (2024) and Passas (2024).

Table 2 shows the distribution of publications by the language used in science communication. Of the total number of 1,364 publications, the vast majority (1,351; 99.04 %) were written in English. The remaining languages, Spanish, Chinese, Turkish, Russian, Persian, Italian, German, and Arabic, are represented by a minimum of one to three publications, which together account for less than 1 % of the total.

Table 1. Source Type

Source Type	Total Publications (TP)	Percentage (%)
Article	659	48,3
Book	384	28,2
Book chapter	119	8,7
Review	106	7,8
Conference paper	96	7,0
Total	**1364**	**100,0**

This distribution indicates the dominance of English in academic discourse, confirming its status as a global scientific language. This observation is consistent with existing research showing an increase in publications in English, even in countries with a different official language, which is often attributed to the authors' desire for greater international coverage and citations (Liu et al., 2020).

The minimal presence of other languages is indicative of both the globalization of the academic environment and possible marginalization of scientific knowledge presented in local languages. This raises important questions about the accessibility and inclusiveness of scientific information, especially in the context of the development of open access and science communication in the global South Conroy, 2023.

Table 2. Languages must be retrieved from the database

Language	Total Publications (TP)*	Percentage (%)
English	1351	99,04
Spanish	3	0,22
Chinese	3	0,22
Turkish	2	0,15
Russian	1	0,07
Persian	1	0,07
Italian	1	0,07
German	1	0,07
Arabic	1	0,07
Total	**1364**	**100.0**

* One document was prepared in dual language.

The analysis of publications is presented in Table 3 and Figure 3 and covers a wide range of scientific disciplines. The largest number of publications was in the social sciences (36.9 %), which confirms a significant focus on the humanities and social aspects of academic research. This may be due to the diversity of topics covered in this field and the interdisciplinary nature of modern scientific approaches.

The second highest was computer science (11.1 %), reflecting the growing importance of digital technologies in science and society. Psychology (7.5 %) and medicine (6.9 %) showed a sustained interest in mental well-being and healthcare, particularly during the post-pandemic period. Engineering (6.6 %), Arts & Humanities (4.9 %), and Business & Management (3.5 %) made significant contributions to the science space.

Less well-represented fields included the Economic Sciences (2.9 %), mathematics (2.6 %), and Environmental Sciences (2.4 %). Many sciences representing a highly specialized focus are often limited by the applied context or level of funding (14.7 %).

This distribution confirms existing bibliometric trends, indicating a disproportionate distribution of academic output between the humanities and exact sciences (Liu et al., 2023), and emphasizes the need for interdisciplinary collaboration and strategic support for less-funded areas.

Table 3. Subject Area

Subject Area	Total Publications (TP)	Percentage (%)
Social Sciences,	503	36,9
Computer Science,	151	11,1
Medicine,	94	6,9
Psychology,	102	7,5
Engineering,	90	6,6
Arts and Humanities,	66	4,9
Business, Management and Accounting,	47	3,5
Economics, Econometrics and Finance,	39	2,9
Mathematics,	35	2,6
Environmental Science,	32	2,4
Other	200	14,7
Total	1364	100,0

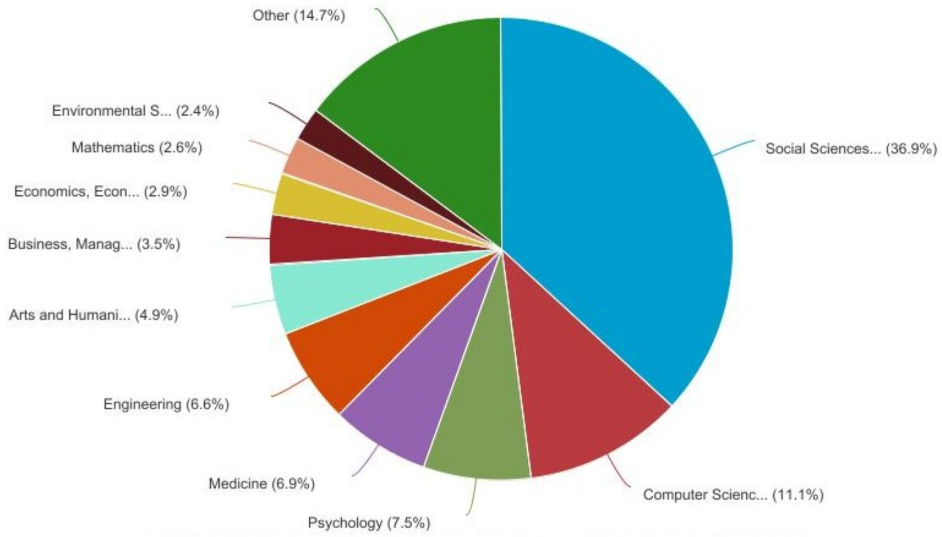

Fig. 3. Subject Area

Table 4 and Figure 4 show the annual statistics of publication activity and citations for the period 2014–2025. The total number of publications was 1,364, of which 1,009 were cited at least once. The total number of citations was 43,294.

The most productive years in terms of the number of publications were 2024 (307 publications) and 2023 (236 publications), which may reflect both an increase in research activity and the development of digital publishing platforms. However, the highest citation rate was observed in 2020, with 101 publications providing 14,414 citations, an average of 28.54 citations per publication and 29.84 per cited publication. This is likely due to global scientific mobilization in response to the COVID-19 pandemic, which is supported by the similar bibliometric results.

The highest Hirsch and g-indices were recorded in 2020, 2022, and 2023, indicating stable citation levels and scientific impact of publications in these years. At the same time, later years (2024–2025) still showed low citation levels, which is natural because of the time lag between publication and the start of active citations.

This analysis emphasizes the need to consider the time factor when assessing scientific productivity, and the importance of combining quantitative and qualitative metrics (such as h- and g-indices) to build an objective bibliometric picture (Passas, 2024: 1517).

The study included the following key bibliometric metrics: total number of publications (TP), number of cited publications (NCP), total citations (TC), average number of citations per publication (C/P), average number of citations per cited publication (C/CP), Hirsch index (h-index) and g-index to assess scientific impact and citation sustainability.

The data show a clear wave-like trend in publication activity, with the highest number of citations concentrated between the turn 2020–2022. This emphasizes the importance of exogenous factors (e.g., pandemics) in shaping scientific interest and publication resonance. Temporal variations in Hirsch and g-indices also indicate differences in the sustainability of scientific contributions over time. The integration of visualized co-author networks and keyword analysis confirmed the growth of interdisciplinary collaboration and the emphasis on health, digitalization, and sustainability during this period.

Table 4. Year of Publication

Year	TP	NCP	TC	C/P	C/CP	AC	h	g
2025	79	16	68	0,86	1,84	37	4	7
2024	307	155	498	1,62	0,37	1342	9	10
2023	236	186	3718	7,88	4,08	912	24	56
2022	172	150	4459	8,64	6,25	714	25	63
2021	149	131	3602	6,04	7,02	513	32	56
2020	101	95	14414	28,54	29,84	483	25	101
2019	87	81	2929	5,61	10,13	289	27	53
2018	75	66	3417	6,51	7,21	474	28	58
2017	68	62	1961	3,60	9,85	199	21	43
2016	41	38	5776	15,65	21,24	272	20	41
2015	28	12	735	2,53	10,65	69	13	27
2014	21	17	1717	7,43	28,62	60	10	21
	1364	**1009**	**43294**	**94,93**	**137,09**	**5364**		

Notes: TP, total number of publications; NCP, number of cited publications; TC, total citations; C/P, average citations per publication; C/CP, average citations per cited publication; AC, Authorcount; h, h-index; g, g-index.

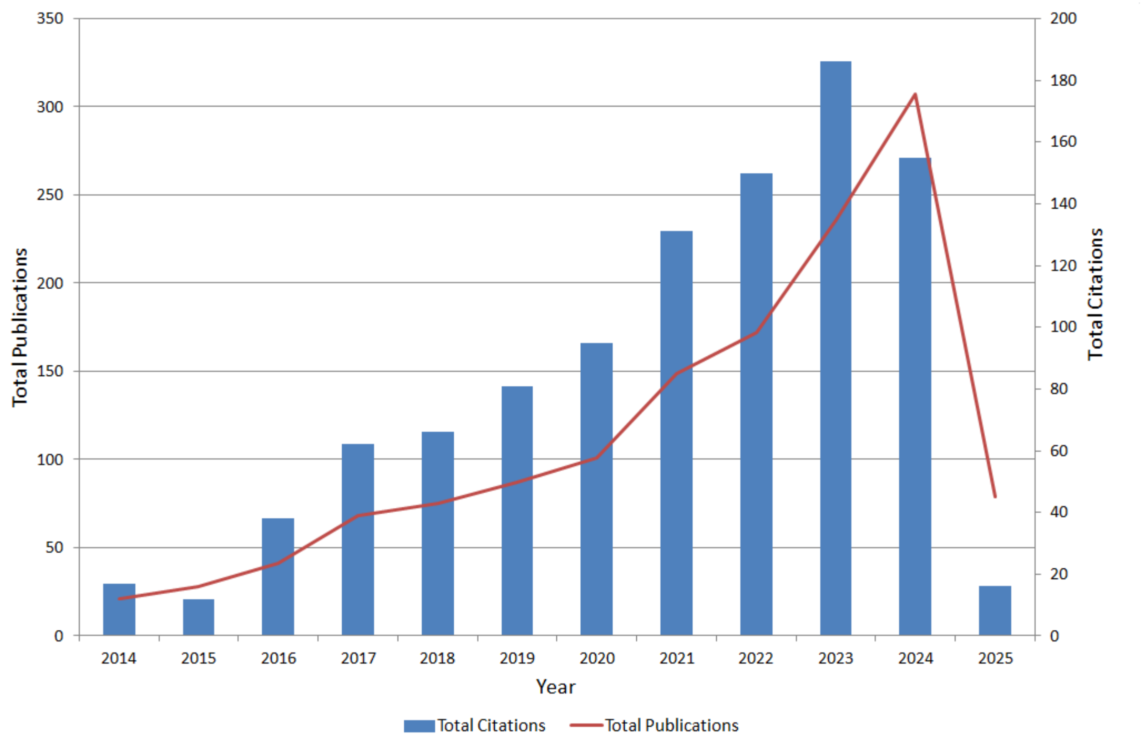

Fig. 4. Total number of publications and citations by year

Table 5 presents an analysis of the top ten countries that have contributed the most to scientific publications on STEAM education, technical thinking, and primary education.

The United States remained the leader in terms of the number of publications (414), followed by the United Kingdom (85), China (75), and Australia (52). At the same time, Germany shows the highest citation rate with 52.38 citations per publication and 59.86 per cited publication, despite its relatively modest volume of publications (40). These findings indicate the importance of high-quality German research in this field.

In terms of scientific impact, the United States also leads in all key indicators: total citations (13,461), Hirsch index (46), and g-index (109). The UK and China form a stable core of scientific activity with high citation levels and comparable indices. The remaining countries – Canada, Spain, India, the Netherlands, Iran, and Canada – show moderate publication and citation activities but confirm the global nature of interest in STEAM in education.

The geographical distribution of publication activity shows a dominance of English-speaking and industrialized countries, with a clear concentration of scientific influence in the US, United Kingdom, China, and Germany. High citation rates with relatively few publications in some countries (e.g., Germany) provide a focused and qualitative contribution to the research agenda. This emphasizes the importance of transnational research cooperation in the field of educational innovation and development of cognitive competence in elementary schools.

After 2020, there has been a steady upward trend in the number of publications, which can be linked to the global focus on digitalization and innovation in education. The geographical distribution shows the dominance of English-speaking countries, such as the US, United Kingdom, and Australia, among the top 15 active countries. The main contribution to publication activity comes from specialized journals in the field of pedagogy and technology as well as from a few leading authors who form the core of scientific citations on the topic.

Table 5. Top 10 Countries contributed to the publications

Country	TP	NCP	TC	C/P	C/CP	h	g
United States	414	339	13461	32.51	39.71	46	109
United Kingdom	85	69	2225	26.18	32.25	23	46
China	75	61	2177	29,03	35.69	19	46
Australia	52	44	1058	20.35	24,05	14	32
Germany	40	35	2095	52.38	59.86	14	40
Spain	31	24	408	13.16	17	8	20
Canada	30	20	378	12,6	18,9	7	19
India	29	18	478	16.48	26.56	7	21
Netherlands	26	22	326	12,54	14.82	10	17
Iran	10	6	86	8,6	14.33	3	9

Notes: TP, total number of publications; NCP, number of cited publications; TC, total citations; C/P, average citations per publication; C/CP, average citations per cited publication; h, h-index; and g, g-index.

Collaboration between institutions and countries: This section analyzes collaboration between institutions and countries, which is often visualized using network maps. This can help identify important research centers and international partnerships. Li et al. (2023) provide an example of how institutional collaboration can be analyzed in bibliometric research.

Analyzing International Research Collaboration

Table 6 presents data on the publication activities of different universities and research centers in international scientific cooperation. The table contains a metric that reflects the strength of cooperative ties with other organizations.

Arizona State University (USA) has the highest number of citations (1200), indicating a high level of scientific impact of its publications. This significantly exceeds the indicators of other institutions despite the identical number of papers in many of them.

Michigan State University (USA) demonstrates the highest strength of cooperation (109) with a relatively low level of citations (17), which may indicate a wide international network of partnerships but an insufficient scientific impact of the publications themselves.

The University of Canberra (Australia) has a moderate number of citations (171) with a relatively high rate of collaboration (21), which indicates balanced scientific activity, both in terms of the quality of publications and interaction with other institutions.

Beijing Normal University (China) has one of the lowest citation rates (5) despite a high co-op rate (67), which may indicate a lack of visibility or impact of their publications in the international research environment.

In terms of geographical distribution, universities from the US are the most active, as evidenced by both the number of organizations in the sample and their citation and co-op metrics.

Some organizations show high connectedness with other institutions but low citations, indicating the need for an in-depth analysis of the quality of scholarly output in the context of international connections.

Universities with high "total link strength (TLS)" values but low citations (e.g., Indiana University and Beijing Normal University) have the potential to increase scientific impact by strengthening the quality of publications and their international visibility.

Table 6. Most influential institutions with minimum of three publications

Organization	Country	Documents	Citations	Total Link Strength
Arizona State University	United States	3	1200	11
The University Of Hong Kong	Hong Kong	3	320	16
University Of Canberra	Australia	3	171	21
Northwestern University	United States	4	98	60
Northwestern University	United States	3	68	27
Johns Hopkins University	United States	3	48	7
North Carolina State University	United States	3	40	54
Utah State University	United States	3	36	24
Indiana University	United States	3	31	69
Michigan State University	United States	4	17	109
University Of Auckland	New Zealand	3	13	14
University Of Central Florida	United States	3	13	43
Purdue University	United States	3	12	25
Beijing Normal University	China	3	5	67
University Of South Africa	South Africa	3		9

Table 7 presents the bibliometric profiles of the 11 most productive authors who made significant contributions to the study of STEAM approaches in primary education and the development of technical thinking.

Table 7. Most Productive Authors

Author's Name	Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
Klapwijk, R.	Delft University of Technology	Netherlands	6	5	53	17,7	8,2	4	6
Rau, M.A.	ETH Zurich,	Switzerland	5	5	270	33,7	220,8	4	5
Yadav, A.	Michigan State University College of Education	United States	5	4	76	15,2	25,3	3	5
Cózar-Gutiérrez, R.	University of Castilla-La Mancha	Spain	4	4	230	46	76, 7	3	4
Franklin, D.	Brigham Young University	United States	4	4	116	14,5	26,4	3	4
González-Calero, J.A.	University of Castilla-La Mancha	Spain	4	4	230	46	76,67	3	4
Runco, M.A.	Southern Oregon University	United States	4	4	702	36,95	702	4	4
Zhu, C.	Delft University of Technology	Netherlands	4	3	35	17,5	5,2	2	4

Author's Name	Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
Hartung, T.	Sanofi Deutschland GmbH	Germany	3	3	245	30,63	24,5	3	3
Leist, M.	Sanofi Deutschland GmbH	Germany	3	3	245	30,63	24,5	3	3
Volpe, J.J.	University of California Irvine	United States	3	3	26	3,25	13	2	3

Notes: TP, total number of publications; NCP, number of cited publications; TC, total citations; C/P, average citations per publication; C/CP, average citations per cited publication; h, h-index; and g, g-index.

The leader in terms of number of publications was Klapwijk (six publications, Delft University of Technology, Netherlands). However, Runco (Southern Oregon University, USA) showed the highest citation rate and the highest average citation rate of the university, with 702 citations of only four publications, corresponding to 36.95 citations per article and 702 citations per cited publication. Rau (ETH Zurich, Switzerland) also scored high, with 270 citations, whereas Cózar-Gutiérrez and González-Calero (both from the University of Castilla-La Mancha, Spain) received 230 out of four publications.

An interesting contribution was made by researchers from the pharmaceutical industry, Hartung and Leist (Sanofi, Germany), who each published three articles with high citation rates (245 citations and C/P > 30), which may indicate an interdisciplinary interest in the topic.

Scientific productivity in STEAM and technical thinking are distributed among academic institutions in the US, Europe, and Asia. The leaders in terms of quality indicators (citation rates) are researchers from the USA, Switzerland, and Germany, confirming their influence on the international research agenda. The significant citation rate of several authors with a small volume of publications indicates the high relevance of their work to the academic community.

Keywords extracted from titles, abstracts, and selected author terms are important indicators of research focus and prioritize topics in the scientific literature. Table 8 and Figure 5 show the keyword overlap analysis, revealing the main semantic clusters in STEAM, technical thinking, and educational publications. The evaluation was based on the number of keyword overlaps (occurrences), the Total Link Strength, the proportion of publications in which the term occurred, and the relative relatedness per publication.

Table 8. Keyword overlap analysis: identifying semantic clusters in STEAM and technical thinking studies

Group	Occurrences	Total link strength	% of publications	TLS for publication
human	197	1711	19,86	8,69
computational thinking	111	365	11,19	3,29
student	106	605	10,69	5,71
literature review	84	84	8,47	1
STEM	78	247	7,86	3,17
education	76	364	7,66	4,79
systematic review	65	144	6,55	2,22
primary school	60	134	6,05	2,23
learning	57	176	5,75	3,09
curriculum	45	224	4,54	4,98
animal	33	292	3,33	8,85
problem solving	30	95	3,02	3,17
educational robotics	26	110	2,62	4,23
teacher training	24	119	2,42	4,96
Total	**992**	**4670**	**100,0**	**60,38**

The key cores of the semantic structure are the terms "human" (19.86 %), "computational thinking" (11.19 %) and "student" (10.69 %), showing high values in terms of both the number of occurrences and connectivity in the semantic network. This confirms the focus on the human-centered approach, role of the learner, and cognitive components of STEAM education.

The performance of the term "animal" (3.33 % of publications, TLS/publication = 8.85) and "human" (TLS/publication = 8.69) indicates a high relatedness of these concepts to other terms, which may be related to the application of STEAM approaches in biology, neuroscience, or behavioral research.

Topics reflecting the methodological aspects of research, such as literature reviews, systematic reviews, and curricula, also feature prominently, demonstrating the high level of formalization and maturity of the research field.

The keyword analysis revealed a consistent semantic structure dominated by themes related to learners, technical thinking, and educational methodologies. The presence of the terms "primary school", "learning", "educational robotics", and "teacher training" confirms the research focus on the practical applications of STEAM in elementary schools. The overall strength of the links (TLS = 4670) and the high overlap of key terms indicate an established but evolving thematic network with a tendency towards interdisciplinary integration and increasing conceptual complexity.

Semantic analysis of the citation network shows how often keywords occur together, revealing clusters of related concepts and new research areas (Mejia et al., 2021, Alreahi et al., 2023).

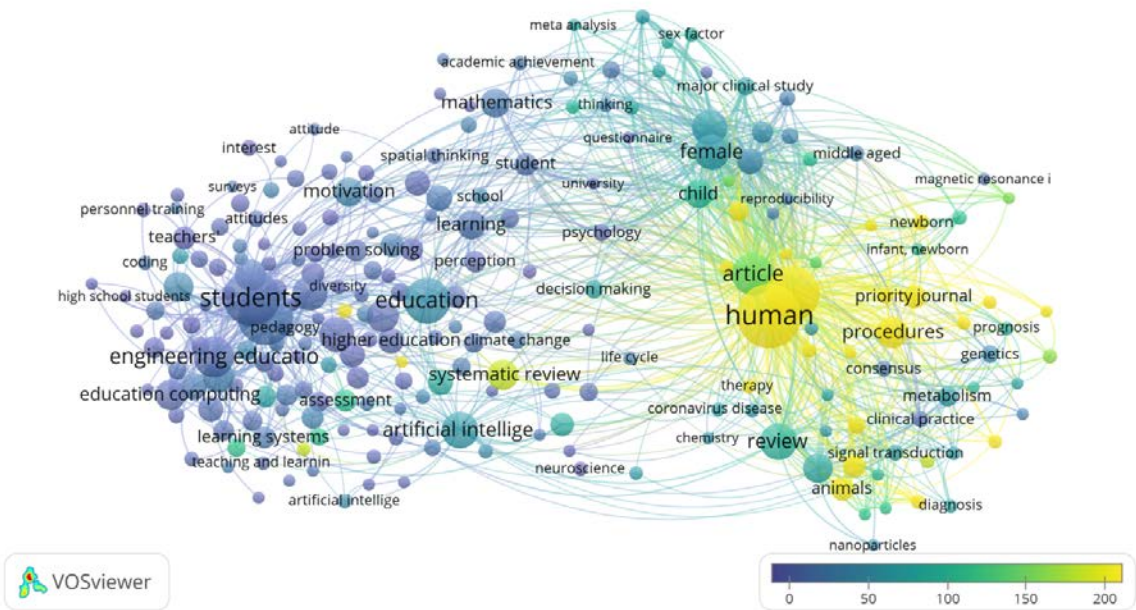

Fig. 5. Network visualization map by author's keywords

Analysis of keyword coincidences demonstrated high coherence in the research area, where the key cores were concepts related to humans, learning, computational thinking, and STEM education. The co-occurrence of terms identified four notional clusters (Figure 6).

(1) Pedagogical and Anthropological

(2) Technological and methodological aspects

(3) Empirical and Educational

(4) Organizational and programming

This structure emphasizes the interdisciplinary nature and conceptual maturity of the research area.

To identify key research areas in the fields of STEAM, elementary education, and technical thinking, we analyzed the frequency of keywords using the VOSviewer software. Only terms that occurred at least 10 times in a sample of 1364 articles were included in the analysis. This resulted in a structured topic map with four clusters, each representing a specific research area.

Visualization: Keyword frequency map

Cluster 1 (red): STEAM approach to education.

Keywords: STEAM, STEM, Education, Course of Study, Pedagogy, Project-based Learning, Integration.

The focus was on the methods of implementing STEAM in primary education, curriculum development, and project-based learning.

Cluster 2 (green): Technical thinking and cognitive development

Keywords: technical thinking, problem solving, creativity, cognitive skills, critical thinking.

Cluster 3 (blue): Information technology and digital tools

Keywords: Technology, Digital Tools, Robotics, Coding, ICT, Educational Software.

This strand relates to the incorporation of digital tools (robotics, coding, etc.) into STEAM education.

Cluster 4 (yellow): Teacher training and professional development

Keywords: Teacher training, professional development, teacher education, educational design.

The main focus was on analyzing the preparation of teachers to work in the STEAM environment and the formation of methodological approaches.

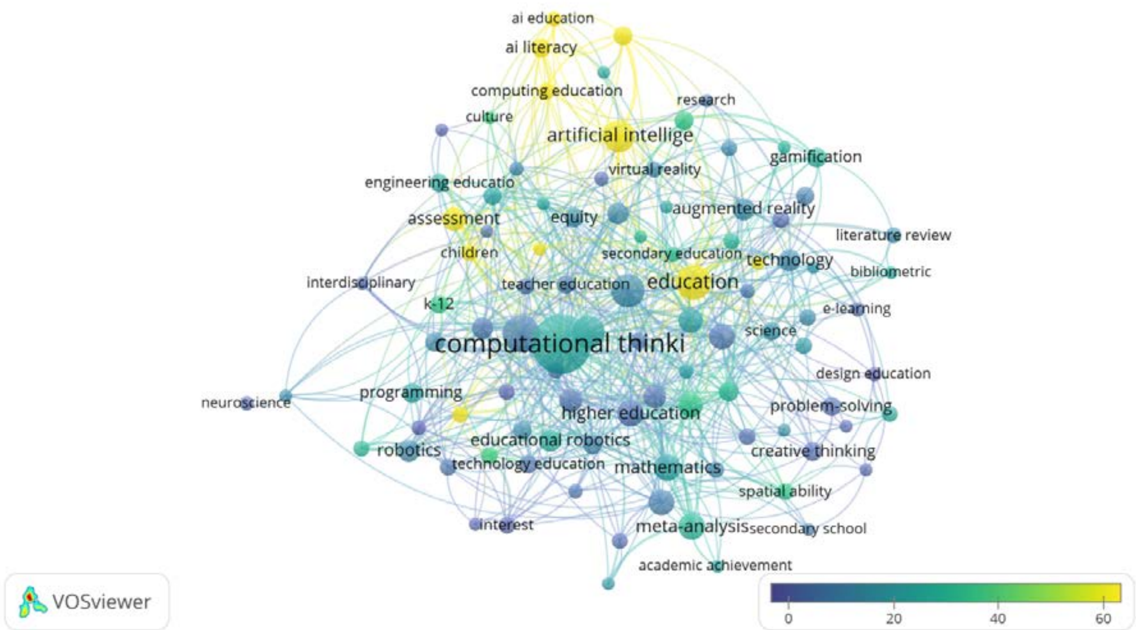

Fig. 6. VOSviewer Visualis creates term-matching networks based on header and abstraction (binary counting) fields

Table 9 presents an analysis of the scientific influence of countries based on the number of publications, total citations, total citation strength, average citations per publication, and integral coherence index. These metrics allow us to assess not only the volume of publication activity but also its qualitative characteristics at the level of an individual country.

The United States of America is the leader in terms of both the number of papers (476) and total number of citations (16,056), accounting for 35.16 % of all publications. However, in terms of citations per publication (33.73), the United States lagged behind several European countries, indicating the prevalence of large rather than score-based highly cited contributions.

Countries with fewer publications showed the most impressive citation averages, but quality weights:

1. Russian Federation: 8 publications, 1968 citations (246 citations per article).
2. Egypt: 8 publications, 1761 citations (220.12 citations per publication).
3. Greece: 22 publications, 3494 citations (158.82 per publication).
4. United Arab Emirates: 13 publications, 1869 citations (143.77 per publication).

These figures demonstrate the focused participation of research groups in highly cited projects, often in collaboration with other authors.

Total Link Strength (TLS) shows the intensity of network links between countries and other participants in the publication process. The United States remains the leader in this indicator (TLS = 332), but Belgium (7.53), Egypt (7.0), and Russia (6.0) show the highest TLS per publication, indicating that these countries are significantly integrated into international research networks.

The data indicate two different types of scientific impacts:

– Highly stable contributions (USA, UK, and China) are characterized by high impact and medium citation rates.

– High Impact Score Contributions (Russia, Egypt, Greece, United Arab Emirates) are characterized by a small number of publications but extremely high citation and network activity.

This configuration emphasizes the importance of international cooperation and strategic publications in journals with high impact factors, as a means of scientifically positioning countries with a limited number of authors.

Table 9. Comparative analysis of countries by total number of publications and citations

Country	Documents	Citations	Total Link Strength	% publications	Citation to the publication of	TLS for publication
United States	476	16056	332	35.16	33,73	0,7
United Kingdom	132	6905	284	9,75	52,31	2,15
Germany	73	5797	228	5,39	79.41	3,12
Italy	40	4173	197	2,95	104,32	4,92
Australia	80	3605	180	5,91	45,06	2,25
Netherlands	46	3079	168	3,4	66,93	3,65
France	27	1562	161	1,99	57,85	5.96
Sweden	24	2868	154	1.77	119,5	6.42
Canada	55	4288	153	4,06	77,96	2.78
Belgium	19	2641	143	1,4	139	7.53
Spain	49	2691	130	3,62	54,92	2.65
China	97	3699	128	7,16	38,13	1.32
Japan	26	2424	123	1,92	93,23	4,73
Switzerland	20	806	88	1.48	40,3	4,4
Brazil	17	731	83	1,26	43	4.88
Israel	19	943	77	1,4	49,63	4,05
Austria	19	2110	75	1,4	111,05	3,95
United Arab Emirates	13	1869	63	0,96	143,77	4.85
India	36	2126	59	2.66	59,06	1.64
Portugal	15	405	57	1,11	27	3,8
Egypt	8	1761	56	0,59	220,12	7
Finland	17	863	56	1,26	50,76	3,29
Greece	22	3494	54	1,62	158,82	2.45
South Korea	16	1764	52	1.18	110,25	3,25
Russian Federation	8	1968	48	0,59	246	6

As part of the bibliometric analysis of publications indexed in the Scopus database, the keywords "STEAM", "elementary school" and "technic think" were used. The analysis was conducted with the help of VOSviewer software, which allowed not only to identify publication activity, but also to assess the level of international cooperation between countries on the basis of Total Link Strength.

The Total Link Strength allows us to determine not only the quantitative involvement of a country in research activities, but also the quality and scale of international cooperation. This is especially true in the context of interdisciplinary topics such as STEAM, where collaboration between countries and disciplines plays a key role in the development of research approaches.

The journal Computers and Education (Elsevier Ltd) also has the highest citation rate with 1264 citations with nine publications, indicating the exceptionally high quality and resonance of the published papers. This journal also has the highest CiteScore (19.8), SJR (3.682), and SNIP (5.21) among the submitted sources (Table 10).

– Education and Information Technologies (Springer): 25 publications, 437 citations, bite score = 10.

– Educational Psychology Review (Springer Nature): High citation rate (415 with eight articles) and highest SNIP (5.38)

– Sustainability (Switzerland): 14 articles and moderate citations (256) reflecting a sustained interest in environmental sustainability and education.

ACM journals reflect the contribution of technical and computational science in shaping STEAM discourse, although their metrics (especially SNIP and SJR) are somewhat lower than pedagogical publications, which are typical of conference proceedings and highly specialized journals.

Source analysis showed that publications in the area of STEAM education and technical thinking were concentrated in journals at the intersection of pedagogy, cognitive science, and technology. Elsevier and Springer journals are key venues for the dissemination of research findings, providing both high coverage and academic impact. Separately, sources demonstrating a high quality-to-quantity ratio, such as Computers and Education and Educational Psychology Reviews, confirm the trend of growing scholarly attention to the digital and cognitive aspects of education.

Table 10. Leading scientific journals in the field of STEAM education and technical thinking

Source Title	TP	TC	Publisher	CiteScore	SJR	SNIP
Thinking skills and creativity	51	815	Elsevier Ltd	7,3	1.162	2,17
Education and information technologies	25	437	Springer	10	1.301	2,31
Frontiers in education	16	121	Frontiers Media SA	2,9	0.64	1,34
Education sciences	15	42	Multidisciplinary Digital Publishing Institute (MDPI)	4,8	0.669	1,32
Sustainability (Switzerland)	14	256	Mary Ann Liebert	6,8	0.672	1,09
International journal of technology and design education	13	167	Springer Science and Business Media B.V.	5,3	0.812	1,54
ACM international conference proceeding series	13	52	Association for Computing Machinery	1,5	0.253	0,23
Computers and education	9	1264	Elsevier Ltd	19,8	3.682	5,21
Educational psychology review	8	415	Springer Nature	15,7	4,32	5,38
ACM transactions on computing education	7	44	Association for Computing Machinery	6,5	1.083	1,91

Notes: TP = total number of publications; TC = total citations.

Table 11 presents the integral bibliometric indicators describing the publication and citation activity of 1364 scientific publications on the topic under consideration for the period 2014–2025.

During the 11 years, 46258 citations were recorded, which is an average of 4205.27 citations per year. The average number of citations per publication was 34.09, indicating steady interest in the scientific community on the topic. The index of citations per author was 13256.56, with an average number of authors per publication of 3.25, which corresponds to the international trend towards the interdisciplinary and collective nature of scientific work.

High values of the Hirsch index (h-index = 80) and g-index (199) confirm the presence of a core of highly cited publications and the stable scientific reputation of the research field. The average number of publications per author, 632.26, is an aggregate statistic that indicates authors' contribution to collective research.

Aggregate metrics demonstrate a high level of scientific productivity and significant number of citations in a publication corpus. These indicators indicate the maturity and relevance of the research area, confirming the active involvement of the international community and the presence of highly cited studies that form the core of this subject. The stable correlation between the number of authors and publications emphasizes the collaborative nature of the research characteristics of interdisciplinary areas such as STEAM and educational technologies.

Table 11. Cumulative publication citation metrics for 2014–2025

Metrics	Data
Publication years	2014–2025
Citation years	11
Papers	1364
Citations	46258
Cites/ years	4205,27
Cites/paper	34,09
Cites/author	13256,56
Papers/author	632,26
Author/paper	3,25
h-index	80
g-index	199

The data in Table 12 reveal key trends in STEM/STEAM education research. The leading position of the publication by Sawyer & Henriksen (2023) in both total citations (1,131) and annual citation rate (565.5) indicates the emergence of a new paradigm that places creativity at the core of the STEAM approach. Similarly, the high annual citation rates of research on artificial intelligence in education (Holmes, Tuomi, 2022: 95.33; Long, Magerko, 2020: 178) reflect the rapid institutionalization of this field.

Table 12. Top-cited publications within the STEM/STEAM education domain

No.	Authors	Title	Year	Cites	Citesper Year
1	R.K. Sawyer, D. Henriksen	Explaining creativity: The science of human innovation	2023	1131	565.5
2	D. Long, B. Magerko	What is AI Literacy? Competencies and Design Considerations	2020	890	178
3	M.A. Runco	Creativity: Theories and Themes: Research, Development, and Practice	2014	521	47.36
4	X. Tang, Y. Yin, Q. Lin, R. Hadad, X. Zhai	Assessing computational thinking: A systematic review of empirical studies	2020	417	83.4
5	W. Holmes, I. Tuomi	State of the art and practice in AI in education	2022	286	95.33

The enduring influence of foundational studies (Runco, 2014: 521) confirms the continuing importance of theoretical frameworks for creativity. Concurrently, there is a growing impact in applied areas such as AI literacy and computational thinking, which demonstrate not only scholarly interest but also practical implementation as measurable educational outcomes.

The predominance of review and conceptual articles among the most-cited publications is characteristic of a consolidation phase in the research field. Monographs contribute to theoretical development, whereas systematic reviews facilitate the transfer of research findings into teaching practices.

The combination of two metrics, the total citation count and annual citation rate, helps distinguish "classical" works with long-term influence from emerging publications that shape current research trends. The identified patterns confirm a shift toward measurable digital and creative competencies, reflecting the field's general orientation toward validated educational outcomes and practice-oriented development.

Thus, the core of contemporary research is formed by three interconnected domains: the theoretical foundations of creativity, the development of AI literacy, and the cultivation of computational thinking as operationalizable educational outcomes for primary schools. These areas collectively represent the evolving research priorities in STEM/STEAM education.

Table 13 shows the distribution of the number of authors per publication in a sample of 1,364 research papers covering STEAM, technical thinking, and elementary education. This parameter allows us to assess the nature of research collaborations, intensity of scholarly interaction, and trends towards individual or team research productivity.

The most common were publications with one (22.4 %) and two (23.26 %) authors, which together accounted for almost half of all the papers (45.7 %). This may indicate a significant share of individual or small-group research, especially in pedagogical and theoretical-methodological directions.

Simultaneously, approximately 18.6 % of the publications had three authors, and the share further decreased as the number of co-authors increased. Nevertheless, publications with large author teams (from 11 to 100 authors) are also represented: seven publications have 100 authors each, and another eight have between 41 and 66 co-authors. These studies are likely based on large-scale international studies, meta-analyses, or global-level projects.

The category with zero authors (1.8 %) was notable, probably due to metadata errors or unstructured information in the database.

The distribution of the number of authors per publication indicated the predominance of individual and small-group research activities in STEAM and education. However, the presence of multi-authored teams indicates a growing trend towards internationalization and interdisciplinarity of research, especially in topics related to global challenges and the integration of technological approaches. This diversity in author formats reflects the flexibility of the research environment and opportunities for both local and large-scale academic collaborations.

Table 13. Number of authors (co-authors) for publication in research

Author Count	Total Publications (TP)	Percentage (%)
1	305	22,4
2	316	23,26
3	254	18,6
4	162	11,9
5	114	8,4
6	53	3,9
7	39	2,9
8	15	1,1
9	11	0,8
10	8	0,6
11–20	31	2,3
21–30	10	0,7
31–40	6	0,4
41–66	8	0,6
100	7	0,5
*	25	1,8
Total	**1364**	**100,0**

* No author is listed.

Table 14 presents data on the key sponsors that provided funding for scientific publications on the subject. Funding reflects not only financial, but also strategic support for the subject by scientific and political institutions, which makes this indicator an important element of bibliometric analysis.

The leader in the number of funded publications was the US National Science Foundation (NSF), with 81 papers (11.4 % of the total number of funded studies). This emphasizes the importance of the STEAM direction in US science policy, particularly in the context of primary and technology-oriented education.

Second, the European Commission (30 publications, 4.2 %) plays a key role in transnational support for research initiatives under *Horizon 2020* and *Horizon Europe* programs. Also making significant contributions are Chinese agencies, the National Natural Science Foundation of China (NSFC) and the Ministry of Science and Technology of the People's Republic of China, which have funded 25–26 publications each, reflecting the active development of digital education initiatives in China.

Other major funding sources include the US National Institutes of Health (NIH), UK Research and Innovation (UKRI), and Ministry of Education and Science of several countries (Germany, Japan, and Australia). This demonstrates the global nature of interest in STEAM topics and their cross-sectoral importance from education to health and technological development.

Funding for publications in the fields of STEAM education and technical thinking is provided by both national scientific foundations and international programmes. The leaders are the USA, European Union, and China, forming the strategic core of global support for innovative education. There is a steady trend towards internationalization of funding, which promotes the development of interdisciplinary and transnational research consortia.

Table 14. The main organizations that sponsor research in the field of STEAM education

No.	Sponsoring organizations	Documents	Percentage (%)
1	National Science Foundation	81	11,4
2	European Commission	30	4,2
3	National Natural Science Foundation of China	26	3,7
4	National Institutes of Health	25	3,5
5	Ministry of Science and Technology of the People's Republic of China	25	3,5
6	UK Research and Innovation	23	3,2
7	U.S. Department of Health and Human Services	22	3,1
8	Horizon 2020 Framework Programme	21	3,0
9	Ministry of Education of the People's Republic of China	12	1,7
10	U.S. Department of Education	11	1,5
11	Bundesministerium für Bildung und Forschung	11	1,5
12	Deutsche Forschungsgemeinschaft	10	1,4
13	Japan Society for the Promotion of Science	10	1,4
14	Australian Research Council	10	1,4
15	Department of Education and Training	10	1,4
	Total sponsors	**711**	**100,0**

5. Discussion

The findings confirm a rapid acceleration of interest in STEAM at the primary-school level. The dataset comprised 1,364 publications for 2014–2025 (after deduplication), with consolidated influence metrics (h = 80; g = 199; 46,258 citations; 34.09 citations per article), indicating a mature and cohesive research core. The 2020 citation peak – despite only 101 publications – likely reflects the pandemic's exogenous push toward digitalization and the subsequent visibility of EdTech research (14,414 citations; 28.54 per paper). The uneven h/g dynamics across 2021–2023 are consistent with citation lag and thematic consolidation captured by our thematic evolution maps, where isolated pedagogical studies increasingly converge with interdisciplinary models.

Geographically, output and impact concentrated rate in settings with robust research infrastructure. The United States leads both by volume and influence, while Germany achieves high citation density with a moderate output, suggesting a smaller but methodologically strong corpus. This center-periphery pattern is broadly consistent with prior bibliometric overviews in STE(A)M education and EdTech, which also reported growth in international collaboration and cross-disciplinary venues (Marín et al., 2021).

Source analysis highlights journals at the intersection of pedagogy and digital technology as major drivers of discourse. Computers & Education exhibits exceptional citation returns (e.g., 1,264 citations across nine papers in our set), while Educational Psychology Review shows the best SNIP performance with fewer items. Together, these venues appear to set evidentiary standards for primary-level STEAM by bridging cognitive psychology and technology-enhanced learning (TEL).

Semantic analysis revealed a stable four-cluster architecture coupling (a) technical thinking/engineering competencies, (b) digital tools, (c) STEAM pedagogical strategies, and (d) cognitive development in early years. The prominence of "teacher training" among highly connected keywords indicates that teacher preparation is not merely contextual but is a topic in its own right. This aligns with cumulative evidence on teacher professional development (PD): the most effective PD integrates content knowledge with techno-pedagogical design (e.g., TPACK), builds in co-planning and reflective cycles, and is associated with more durable classroom uptake (Huang et al., 2022; Surahman, Wang, 2023; Fabian et al., 2024). Attitudinal factors – teachers' trust in and perceived usefulness of digital and AI-supported tools – also shape actual classroom integration at the primary level (Ayanwale et al., 2024). In parallel, early years practice frameworks underscore age-appropriate design-as-play approaches for engineering concepts in the primary grades (Fleer, 2020).

Simultaneously, our journal-topic profiles surface a tension between cognitive effectiveness and operational feasibility. High-frequency terms, such as human, student, and computational thinking, signal a shift toward measurable learning outcomes and learner-centered designs. However, the "digital tools" cluster (robotics, coding, ICT) presupposes infrastructure that primary schools secure unevenly. As noted in policy-level syntheses, inequities in access can amplify pre-existing gaps unless schools employ realistic low-tech→high-tech trajectories (paper engineering and 2D→3D modeling before visual programming and robotics), flexible provisioning models (e.g., BYOD), and compensatory measures to mitigate the digital divide (UNESCO, 2023; OECD, 2023; McLean, 2016; Schmitz et al., 2024). In this light, the visibility of the "tech cluster" within our maps suggests that access strategies are moving from background constraints to mainstream research.

Two differences stand out compared with earlier bibliometric studies. First, a primary school focus magnifies learner-centered and pedagogical-method components (e.g., teacher training and curriculum design), which is unsurprising given age-specific demands for safety, didactics, and assessment. Second, the share of digital topics (robotics, coding, AI in education) is higher, consistent with a post-pandemic "digital normal" and institutionalization of EdTech in early grades.

Methodological considerations. The presence of highly cited but thematically distant review articles among "top cites" likely reflects broad search settings and a common bibliometric trade-off between recall and topical precision in the literature. Future iterations should refine field restrictions (e.g., education-domain filters; TITLE-ABS-KEY tuning) to curb cross-domain bleed-throughs. Year-by-year shifts should also account for citation lags and exogenous shocks, which can inflate specific periods and topical nodes.

Practical implications for primary schools are discussed. Teacher readiness is an independent driver of sustainable STEAM integration. PD should explicitly link content and techno-pedagogical lesson design, supported by mentoring and collaborative reflection (Huang et al., 2022; Surahman, Wang, 2023; Fabian et al., 2024; Fleer, 2020). Technology access should be treated as a designed trajectory rather than a fixed state: low-tech 2D→3D solutions scaling to high-tech robotics/coding under budgetary, maintenance, and regulatory constraints (UNESCO, 2023; OECD, 2023; McLean, 2016; Schmitz et al., 2024). Finally, credible evaluation of technical and spatial thinking requires validated measurement instruments; current empirical work remains uneven, which helps explain why review- and method-oriented publications dominate the highly cited core.

Limitations and future directions. The reliance on a single index (Scopus), English-language emphasis, and specific query fields constrain coverage and may shape the top-cited set. Promising next steps include (a) reruns with more precise education-domain filters, (b) triangulation with systematic reviews on PD and infrastructure in primary schools, and (c) stratification by school type/region to examine technology access as a moderator of outcomes.

6. Research gaps and future research directions

Recent studies have highlighted the increasing emphasis on computational thinking and artificial intelligence in primary STEAM education. This trend signifies a broader acknowledgment of the need to equip young learners with the competencies required to navigate increasingly digital and automated environments (Saputra, 2025). Educators are incorporating coding, algorithmic thinking, and problem-solving activities into early curricula to cultivate logical reasoning and creativity (Juškevičienė et al., 2020; Asunda et al., 2023: 51).

Tools such as blk-based programming platforms and AI-powered educational applications are being used to render abstract concepts more accessible and engaging for children. These initiatives aim to establish foundational competencies that support lifelong learning and adaptability in a rapidly evolving technological landscape (Mamaeva et al., 2020; Dohn et al., 2022). Looking ahead, future directions in primary STEAM education are likely to emphasize interdisciplinary learning environments that blend digital literacy with the ethical and societal considerations of technology. As artificial intelligence has become increasingly embedded in daily life, there is a growing need to introduce age-appropriate discussions on data privacy, algorithmic bias, and responsible technology use.

In addition, personalized learning powered by AI is expected to gain traction by offering tailored educational experiences that address individual students' needs and learning styles. These developments suggest a continued evolution of STEAM education towards more holistic, inclusive, and forward thinking.

7. Conclusion

A bibliometric analysis of publications in the Scopus database for 2014-2025 has revealed key trends, research priorities, and the dynamics of scientific activity in the fields of STEAM education, primary school, and technical thinking. In the context of rapid technological development and the emphasis on preparing students for the challenges of the 21st century, the STEAM approach is becoming increasingly relevant, starting from the primary level of education.

This study focused on the integration of interdisciplinary approaches, digital technologies, and cognitive development of primary school students. Simultaneously, there is growing interest in the formation of technical thinking, especially through project activities, robotics, and the use of digital educational resources.

Despite these positive dynamics, questions remain regarding the uneven development of research in different countries, lack of systematic reviews, and poor presentation of empirical studies aimed at measuring the actual impact of STEAM on students' thinking and learning outcomes.

Highlights

Bibliometric analysis of 1,364 publications on STEAM education and technical thinking from 2014 to 2025.

The United States, United Kingdom, and China are the most productive countries in STEAM research.

Arizona State University, University of Hong Kong, and the University of Canberra are influential institutions.

Keyword analysis revealed four research clusters: pedagogical, technological, empirical, and organizational.

Computational thinking and AI are becoming increasingly important in primary STEAM education.

Future research should focus on theoretical models, effectiveness evaluations, and inclusive approaches.

Interdisciplinary learning environments that blend digital literacy with ethics are crucial for STEAM education.

Prospects for future research

Based on this analysis, we identified several promising areas for further research.

1) Development of theoretical models of technical thinking in the context of STEAM education, especially for younger students.

2) The effectiveness of the STEAM approach was evaluated through experimental and longitudinal studies (e.g., using cognitive tests and thinking scales).

3) Impact of digital and gaming technologies on the development of creativity and engineering thinking.

4) Cross-cultural comparative studies on STEAM implementation in countries with different levels of educational development.

5) Integrating gender perspectives and inclusive approaches into the business practices of primary education.

6) Barriers to preparing primary school teachers to implement STEAM programs and develop effective models of professional development.

Ethical Approval

This study did not involve any research involving human participants, identifiable human data, human biological materials, or animals. As such, ethical approval from an institutional review board or ethics committee is not required. This study adhered to the accepted guidelines for non-intervention and desk-based research, involving publicly available secondary data.

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