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Science mapping research of STEM in primary schools: A bibliometric analysis from Scopus database (2004-2024)

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Abstract

STEM education has been garnering increasing global attention. Implementing STEM education for primary school students serves as a critical starting point to ignite their interest and enthusiasm for learning, while simultaneously fostering the development of essential skills from an early age. To provide an overview of the issues related to STEM in primary schools as represented in publications indexed in the Scopus database, a bibliometric analysis of 967 publications from 2004 to 2024 was conducted. The findings indicate a significant surge in publications on STEM in primary schools from 2019 to 2023. The USA emerges as the most prominent country in the collection, excelling in the number of publications, citations, affiliations, and authors with the highest contributions. The ASEE Annual Conference and Exposition is identified as the leading conference proceeding in terms of publication volume. By analyzing keywords and examining the content of the most influential publications in the collection, four main research trends in STEM education for primary schools were identified: integration of STEM into the curriculum; development of self-directed learning skills in primary education; exploration of the potential of technology in teaching; and program development and teacher training, with a focus on addressing gender and social biases related to STEM. Differences in research trends across various groups were also highlighted. The study's findings provide valuable insights for individuals and institutions while contributing significantly to advancing STEM education, addressing current challenges, and fostering comprehensive societal development in the future.

Keywords: bibliometric, Scopus, STEM, STEM in primary school, primary school

INTRODUCTION

In the Fourth Industrial Revolution era, science, technology, engineering, and mathematics (STEM) education has become one of the top priorities for educators worldwide (Leea et al., 2019). It is regarded as vital to equipping students with essential skills for success in a rapidly changing, technology-driven world (Tanalol et al., 2023). A distinctive feature of STEM education is its interdisciplinary nature, where subjects are integrated rather than taught in isolation. This integration enables learners to connect knowledge across disciplines to solve real-world problems in specific contexts (Yesnazar et al., 2024). Such an approach deepens students' understanding of the relationship between theory and practice, fosters problem-solving abilities, encourages creative thinking, and cultivates skills essential for the future (Zoller, 2011).

Although STEM education emerged only in the 1990s, it has garnered significant attention from scholars over the past two decades. Efforts have been made to integrate STEM education across all levels of education, particularly in primary schools. The term "primary school" is commonly used in countries where British English refers to the first stage of compulsory education for children aged 5 to 11. In contrast, in countries where American English is prevalent, the equivalent term is "elementary school," which typically encompasses students from grades 1 through 5 or 6. Experts argue that primary education is a stage where children's brains

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Contribution to the literature

- This study presents the first comprehensive bibliometric analysis of case study research in STEM education using data from the Scopus database.
- It highlights global research trends, key contributors, influential publications, and thematic developments from 2006 to 2022, offering a quantitative perspective previously absent in the literature.
- The study enhances scholarly understanding by identifying dominant research directions—such as STEM in higher education, STEAM expansion, and K–12 practices—and providing a foundation for future investigations in this evolving field.

develop rapidly, and their curiosity and desire to explore the world are at their peak. Implementing STEM in primary education provides an ideal opportunity to nurture and develop scientific and technical thinking among students (Nantsou & Tombras, 2022). Consequently, introducing STEM to children in the early years of primary education has been strongly advocated and implemented by many researchers (Chaya, 2024). According to Ponte Lira et al. (2024), STEM activities involving exploration and experiential learning spark curiosity and interest in students. These problem-solving activities stimulate creativity, enhance logical thinking, and promote teamwork and collaboration skills (Zoller, 2011). STEM makes learning more engaging and less abstract, laying a solid foundation of knowledge and skills for pursuing STEM education at higher levels (Becker & Park, 2011).

Implementing STEM in primary schools is often more feasible than at other educational levels due to the simplicity of content, accessibility of learning tools (Wan et al., 2023), and a stress-free learning environment without the pressure of examinations (Faigawati et al., 2023). Additionally, the aesthetic and emotional aspects of learning have gained increasing emphasis and are seen as critical components for fostering comprehensive student development, including creativity (Tae, 2018). This emphasis has led to the evolution of STEAM education, which incorporates Arts into STEM and has recently garnered significant interest among researchers (Quigley et al., 2019). Moreover, global and national policies have played an essential role in promoting the application of STEM at this educational level.

Given the significant role of STEM education and the advantages of its implementation, many studies have reviewed various aspects of STEM in primary schools. For instance, Purnama et al. (2023a), based on an analysis of 906 articles from the Scopus database, identified a blended learning model in science education at primary schools, combining synchronous-asynchronous technology, information and communication technology, technological pedagogical content knowledge, multimedia, and Android-based tools for planning and evaluation. The flipped classroom model emerged as the most commonly used approach. In recent publications, the same authors conducted a literature review on web-based e-learning in elementary schools (Purnama et al., 2023b). Larkin and Lowrie (2023) reported findings from a systematic qualitative literature review focusing on STEM education for children aged 4-12 in formal education contexts.

Teacher professional development in STEM education has also been a focal area for researchers. Boz (2023) and Abd Ghani et al. (2023) reviewed training programs for primary school teachers to implement STEM education. Bibliometric studies have also examined STEM-related research in education, such as Khalil et al. (2024), who analyzed data on K12 students from the Web of Science database, and Tuyet et al. (2024), who explored primary schools in Southeast Asian countries using Scopus data. However, these studies either focused on multiple educational levels or were confined to specific regions, and no comprehensive bibliometric analysis has been conducted on all publications related to STEM in primary schools. This distinction may influence curriculum design, as certain cognitive characteristics specific to the primary school age group could be overlooked. Moreover, researching a global scale enables the identification of effective practices implemented across different countries. Such insights facilitate mutual learning and adaptation, allowing nations to develop more appropriate and effective curricula tailored to their educational contexts.

To address this gap, this study aims to comprehensively evaluate research trends and the development of STEM education in primary schools using data from the Scopus database. Specifically, it seeks to answer the following research questions:

RQ1. What are the annual trends and growth patterns in publications on STEM in primary schools?

RQ2. Which countries, institutions, and authors have contributed the most in terms of publications and citations to this topic?

RQ3. Which sources publish the most articles on STEM in primary schools?

RQ4. What topics are addressed in the most influential publications on STEM in primary schools?

RQ5. What are the research trends in STEM in primary schools?

The results of this study provide an overview of research on STEM education in primary schools,

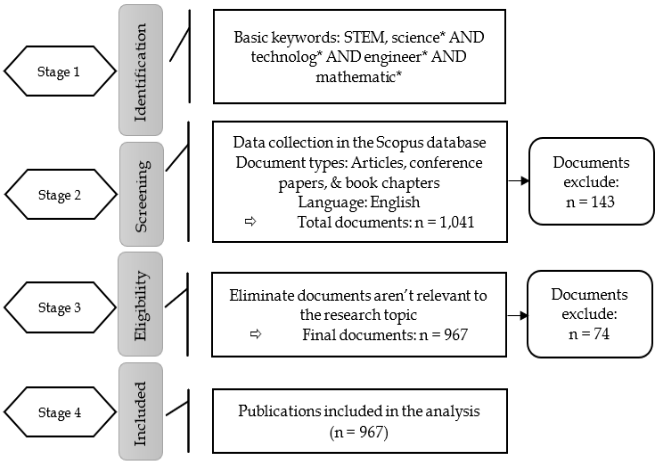

Figure 1. PRISMA flowchart of data collection process (Source: Authors' own elaboration)

Table 1. Main information about data

Description	Results
Timespan	2004:2024
Sources (journals, books, etc.)	465
Documents	967
Annual growth rate (%)	22.46
Document average age	3.92
Average citations per document	8.325
References	35,911
Authors	2,902
Authors of single-authored documents	101
Single-authored documents	112
Co-authors per document	3.57
International co-authorships (%)	12.10
Article	519
Book chapter	71
Conference paper	377

outlining the key trends and future directions for this field. These findings serve as an essential foundation for researchers, educational administrators, and stakeholders to propose research directions, policies, and strategies to enhance the effectiveness of STEM education in the current educational context.

METHOD

In this study, the authors conducted a bibliometric analysis using data collected from the Scopus database. This method employs a quantitative approach to describe, evaluate, and monitor published research, ensuring objectivity and transparency and avoiding the biases commonly associated with qualitative methods (Zupic & Čater, 2015). Consequently, bibliometric analysis has become a widely used approach for assessing scientific development across various fields of research (Hallinger & Chatpinyakoop, 2019). The authors selected Scopus as the data source due to its comprehensive coverage, high quality, and reliability (Falagas et al., 2008). Scopus is also the largest and most widely used database for social sciences, making it an ideal choice for this study (Hallinger & Nguyen, 2020; Pham-Duc et al., 2021).

Figure 1 presents the PRISMA flow diagram illustrating the data collection process for STEM in primary schools. The search query included keywords related to education, learning, and teaching, combined with the domains of STEM or the acronym STEM. Exclusion keywords were referenced from the study by Phuong et al. (2023). The query was restricted to the primary school level, and document types were limited to journal articles, conference proceedings, and book chapters written in English. 1,041 documents were retrieved from the query and analyzed using Biblioshiny and VOSviewer, two prominent tools commonly used for data analysis and visualization. Biblioshiny facilitates descriptive analyses, chart generation, and visualization of relationships, providing a comprehensive overview of the research landscape (Aria & Cuccurullo, 2017). Meanwhile, VOSviewer generates visualized networks of scientific collaboration. By analyzing the detailed network of keywords and the relationships among studies, this software enables the identification of key research trends (van Eck & Waltman, 2010).

RESULTS

General Information and Publication Trends

The general information about the collected dataset on STEM in primary schools is summarized in **Table 1**. According to **Table 1**, 967 documents were collected from 465 sources, including articles, book chapters, and conference papers. 2,902 authors contributed to these publications, including 101 authors of single-authored docs and 112 single-authored documents. The remaining documents involved collaborations among authors, with an average of 3.57 co-authors per document and an international co-authorship rate of 12.1%. Although publications on STEM in primary schools first appeared in the Scopus database in 2004, the number of documents and citations has increased rapidly, with an average document age of 3.92 years, average citations per document of 8.325, and an annual growth rate of 22.46%.

Based on Scopus data, the h-index of the dataset is 44, meaning that out of 967 publications, 44 have been cited at least 44 times. The growth trend of publications from 2004 to 2024 is depicted in **Figure 2**. The total cumulative number of citations is 8,050, resulting in an average of 383.3 per year. Based on the number of publications and the increase and decrease of published publications over the years shown in **Figure 2**, we divide the growth trend into three main stages. The first five-year period (2004-2008) saw only six publications on this topic. During the subsequent period (2009-2014), there was an increase, with 66 publications, although the growth rate was inconsistent. From 2015 to 2023, the number of publications increased significantly, with the most rapid

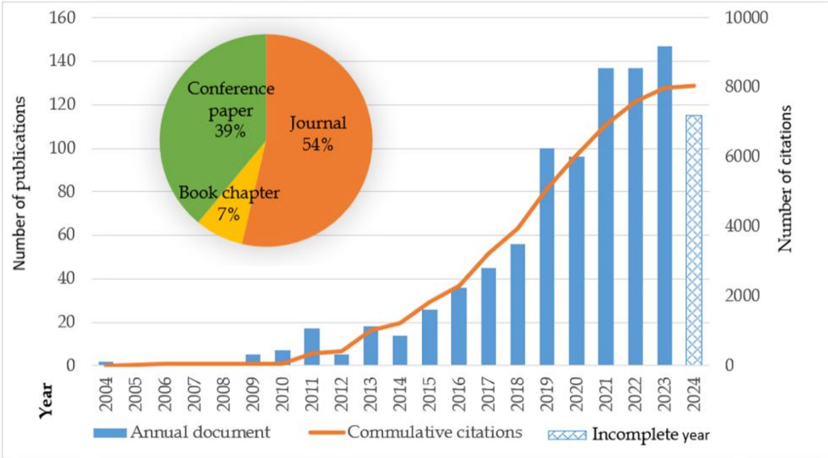

Figure 2. The cumulative annual number of publications and citations of STEM in primary school (Source: Authors' own elaboration)

Table 2. Top 10 countries with the most publications on the topic of STEM in primary school

Rank	Country	Total publications	Percentage (%)	Total citations	Percentage (%)	SCP	MCP
1	The USA	278	28.7	1,994	24.8	115	7
2	Indonesia	77	8.0	81	1.0	34	4
3	Australia	69	7.1	454	5.6	48	5
4	China	56	5.8	510	6.3	27	4
5	Malaysia	43	4.4	226	2.8	20	3
6	The UK	42	4.3	426	5.3	12	3
7	Turkey	37	3.8	261	3.2	18	2
8	Greece	34	3.5	145	1.8	11	3
9	Spain	32	3.3	150	1.9	16	3
10	Hong Kong	31	3.2	160	2.0	21	1

Note: SCP: Single country publications & MCP: Multiple country publications

growth occurring from 2019 onwards. Publications during this period accounted for 75.7% of the total publications on the entire dataset.

Contributions by Country

The Scopus data revealed that 103 countries have contributed publications on STEM in primary schools. Information about the top 10 countries with the highest number of publications on this topic is summarized in **Table 2**.

According to **Table 2**, the USA dominates the top 10 countries with the most publications and citations, contributing 278 publications (28.7% of the collection) and 1,994 citations (24.8% of total citations). This number is nearly four times greater than the second-ranked country. Four countries in the rankings represent Asia: Indonesia (77 publications), China (56 publications), Malaysia (43 publications), and Hong Kong (31 publications), ranked 2nd, 4th, 5th, and 10th, respectively. Australia occupies 3rd place with 69 publications. European countries rank 6th to 9th, with publication counts ranging from 32 to 42.

The ranking for total citations differs significantly from that of total publications. While Indonesia ranks 2nd in publication count, it ranks last in citations.

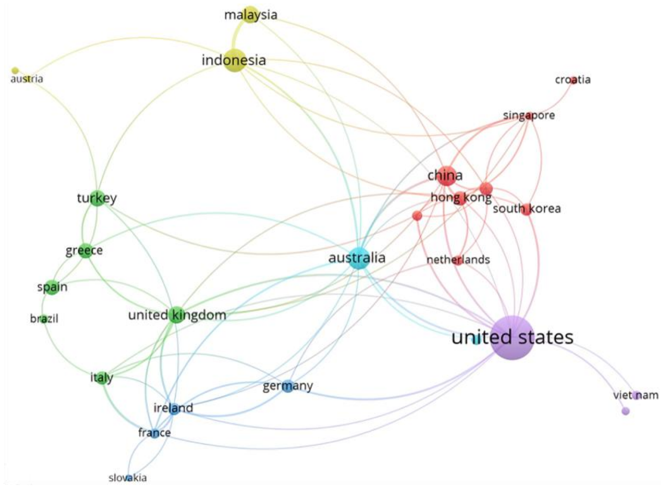

Figure 3. Transnational cooperation network of 28 partner countries (Source: Authors' own elaboration, using VOSviewer)

Conversely, Hong Kong, with the lowest number of publications in the top 10, ranks 7th in total citations. China, Australia, and the UK hold 2nd, 3rd, and 4th places in total citations, with notable gaps compared to the bottom five countries in the ranking.

Collaboration among authors was conducted both within single countries and internationally. **Figure 3** illustrates the international collaboration network in

Table 3. Top 10 affiliations with the highest number of publications on the topic of STEM in primary school

Rank	Affiliation	Country	Number of publications	Citation
1	Universitas Pendidikan Indonesia	Indonesia	19	40
2	The Education University of Hong Kong	Hong Kong	18	70
3	Purdue University	The USA	15	403
4	NC State University	The USA	12	141
5	Texas A&M University	The USA	12	269
6	Universiti Kebangsaan Malaysia	Malaysia	11	114
7	South China Normal University	China	11	79
8	Universiti Pendidikan Sultan Idris	Indonesia	11	68
9	Virginia Polytechnic Institute and State University	The USA	10	69
10	Curtin University	Australia	10	156

publications on STEM in primary schools. Countries included in **Figure 3** have at least seven publications on the topic. The nodes and links in **Figure 3** represent countries and their collaborative relationships. The node size corresponds to the number of publications from that country, while the node color indicates the cluster of associated countries. The thickness of a link reflects the degree of collaboration between countries.

The international collaboration network in **Figure 3** highlights four main clusters: purple, yellow, green, and blue. All countries listed in **Table 2** appear in the network, with the USA, China, Australia, and Indonesia standing out as highly collaborative nations. The purple cluster represents the USA's intercontinental collaborations with Asian, European, and Oceania countries. The green cluster predominantly reflects collaborations among European nations, while the red cluster focuses on Asian countries. The yellow cluster encompasses several Southeast Asian nations.

The ranking for total citations differs significantly from that of total publications. While Indonesia ranks 2^{nd} in publication count, it ranks last in citations. Conversely, Hong Kong, with the lowest number of publications in the top 10, ranks 7^{th} in total citations. China, Australia, and the UK hold 2^{nd}, 3^{rd}, and 4^{th} places in total citations, with notable gaps compared to the bottom five countries in the ranking.

Collaboration among authors was conducted both within single countries and internationally. **Figure 3** illustrates the international collaboration network in publications on STEM in primary schools. Countries included in **Figure 3** have at least seven publications on the topic. The nodes and links in **Figure 3** represent countries and their collaborative relationships. The node size corresponds to the number of publications from that country, while the node color indicates the cluster of associated countries. The thickness of a link reflects the degree of collaboration between countries.

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Contributions by Affiliations

The dataset indicates that authors contributing to research on STEM in primary schools represent 160 different affiliations. The top 10 affiliations with the highest number of publications are listed in **Table 3**. Universitas Pendidikan Indonesia (Indonesia) ranks first in the number of publications but last in citations. Another Indonesian institution, Universiti Pendidikan Sultan Idris, ranks 8^{th} in the top 10. The second-highest affiliation is The Education University of Hong Kong, with 18 publications. When examining affiliations by country, the USA leads with four institutions contributing 49 publications. Purdue University and Texas A&M University rank 1^{st} and 2^{nd} in citations, respectively. Purdue University has 403 citations, 226 of which stem from Capobianco et al. (2011). Similarly, Texas A&M University's total of 269 citations includes 101 citations from Approach et al. (2015). Curtin University (Australia), despite ranking last in the top 10 for publications, ranks 3^{rd} for citations. The remaining affiliations include institutions from Malaysia and China, each contributing 11 publications.

Contribution by Authors

The dataset includes 2,902 authors contributing to 967 publications. **Table 4** highlights the top 12 authors with the most publications on STEM in primary schools. Accordingly, all publications by the top 12 authors were published between 2015 and 2021. The USA has the most authors, publications, and total citations in the top 12. Regarding the number of publications, the two leading authors are also from the USA. Jeon, M. tops the list with eight publications, including seven conference proceedings and one journal article, the latter contributing the most to the author's total citations. Although Quek, F. ranks second in the number of publications, this author has the highest total citations (222), driven by the article "Making the maker: A means-

Table 4. Top 12 authors with the most publications on the topic of STEM in primary school

Rank	Author	Institution/country	Total publications	Total citations	PY_start
1	Jeon, M.	USA	8	82	2017
2	Quek, F.	USA	7	222	2015
3	Chiang, F.-K.	China	7	58	2019
4	Li, X.	China	6	82	2019
5	Scaradozzi, D.	Italy	6	20	2021
6	Zhang, Y.	China	6	96	2019
7	Barnes, J.	USA	5	71	2017
8	Muntean, C.	Ireland	5	61	2017
9	Vasey, E.	USA	5	71	2017
10	Chu, S. L.	USA	5	216	2015
11	Koul, R.	Australia	5	61	2018
12	Dam, L.	Indonesia	5	15	2019

Table 5. Top 10 sources with the highest number of publications on the topic of STEM in primary school

Rank	Sources	Type	Total publication	Total citation
1	ASEE Annual Conference and Exposition, Conference Proceedings (AACE)	CP	54	187
2	Journal of Physics: Conference Series (JPCS)	CP	43	129
3	ACM International Conference Proceeding Series (ACM ICP)	CP	23	55
4	Proceedings of the International Astronautical Congress (IAC)	CP	17	3
5	AIP Conference Proceedings (AIP)	CP	15	18
6	Frontiers in Education (FE)	JN	15	52
7	IEEE Global Engineering Education Conference, EDUCON (IEEE)	CP	14	86
8	Lecture Notes in Computer Science (LNCS)	JN	14	22
9	Education Sciences (ES)	JN	13	76
10	International Journal of Technology and Design Education (IJTDE)	JN	13	334

to-an-ends approach to nurturing the maker mindset in elementary-aged children," which alone received 101 citations. This article also propelled Quek, F. and Chu, S. L. to the top regarding citations. Tied for second place with seven publications is Chiang, F.-K. from China. The third-ranking contributors include Scaradozzi D. from Italy and two Chinese authors, Li, X. and Zhang, Y. The remaining authors in the top 12 each contributed five publications. The sole Southeast Asian representative, Dam, L. from Indonesia, ranks last in the top 12 for the number of publications and total citations.

Collaboration among authors occurred both within and across countries. For instance, five publications involved collaboration among the USA authors Jeon, M., Quek, F., Vasey, E., Chu, S. L., and Barnes, J. Similarly, the three Chinese authors collaborated on one or two publications. Furthermore, six of the 12 top authors participated in international collaborations, contributing to 17 publications.

Journals Publishing

The dataset includes publications from 160 sources on STEM in primary schools. **Table 5** lists the top 10 sources with the highest number of publications.

More than half of the top 10 sources are conference proceedings, while the remaining four are journals with high rankings (Q1 and Q2). Publications from these 10 sources account for 22.9% of the total publications on the topic. The most prolific source is AACE, with 54 publications focusing on technical education and the application of technology in teaching. JPCS ranks second with 43 publications, primarily comprising conference proceedings on physics. ACM ICP ranks third with 23 publications, specializing in information technology and computer science. The remaining sources contribute between 13 and 17 publications.

The ranking by total citations differs significantly from the number of publications. IJTDE, which ranks last in publication count, has the highest total citations (334). 88 citations stem from the article "Investigating the use of robotics to increase girls' interest in engineering during early elementary school." In contrast, IAC, ranked fourth by the number of publications, has the lowest citation count, with most articles remaining uncited. Similarly, AIP has 11 out of its 15 articles yet to be cited. Despite being a relatively recent source (publishing on the topic only since 2021), FE has already achieved 52 citations. AACE and JPCS rank second and third in citations, respectively. Other sources range from 22 to 86 citations. Of the 160 sources, 111 are journals, and 49 are conference proceedings. **Figure 4** presents the quality distribution of publication sources from 2019 to 2024. **Figure 4** shows a significant increase in Q1 and Q2 sources in recent years, particularly Q1 journals. The number of articles on STEM in primary schools published in Q1 journals in 2023 is 2.7 times higher than in 2019, while Q2 publications have more than doubled. In contrast, Q3 journals showed a slight decline, and Q4

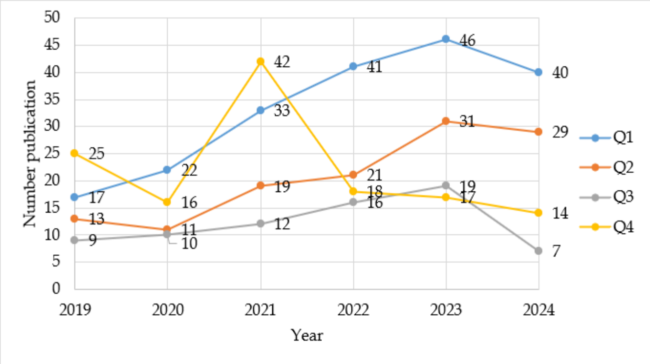

Figure 4. Number of publications in journals by ranking in the period 2019-2024 (Source: Authors' own elaboration)

publications in 2023 decreased by 1.8 times compared to 2019.

Information on Publications and Citation Counts

The collected dataset reveals that the 967 publications on STEM in primary schools have received 8,085 citations. The top 11 most-cited publications account for 17.9% of all citations. Among the journals publishing these 11 influential papers, 10 are ranked as Q1 and one as Q2. **Table 6** provides general information on these publications.

The most highly cited publication is by Capobianco et al. (2011), with 226 citations. This study emphasizes the significance of elementary students' perceptions of engineering careers in informing curriculum development for technical education. It also proposes integrating engineering concepts into K12 education to enhance technological literacy and students' interest in STEM fields.

The publication by Master et al. (2017), although slightly behind in total citations (223), has the highest TC/year (total citations per year) value. This research highlights the importance of equitable educational environments and activities to encourage all primary students, especially girls, to develop their potential in STEM. Similarly focused on girls in elementary education, the work of Archer et al. (2013) received 207 citations and ranks third in TC/year. This study explores the complex social, cultural, and economic factors influencing why many girls who enjoy science do not aspire to STEM careers, advocating for gender stereotype changes to promote equal opportunities.

The following three studies, ranked 4th to 6th in citations, affirm the benefits of design and creativity activities for developing students' skills and thinking abilities. English and King (2015) provide opportunities

Table 6. Top 11 most-cited publications on the topic of STEM in primary school

Rank	Document title	Journal title	TC	TC/Y	APA citation
1	What is an engineer? Implications of elementary school student conceptions for engineering education	Journal of Engineering Education	226	16.1	Capobianco et al. (2011)
2	Programming experience promotes higher STEM motivation among first-grade girls	Journal of Experimental Child Psychology	223	27.9	Master et al. (2017)
3	'Not girly, not sexy, not glamorous': Primary school girls' and parents' constructions of science aspirations1	Pedagogy, Culture and Society	207	17.3	Archer et al. (2013)
4	STEM learning through engineering design: Fourth-grade students' investigations in aerospace	International Journal of STEM Education	150	15.0	English and King (2015)
5	Scalable game design: A strategy to bring systemic computer science education to schools through game design and simulation creation	ACM Transactions on Computing Education	138	13.8	Repenning et al. (2015)
6	Making the maker: A means-to-an-ends approach to nurturing the maker mindset in elementary-aged children	International Journal of Child-Computer Interaction	101	10.1	Approach et al. (2015)
7	Investigating the use of robotics to increase girls' interest in engineering during early elementary school	International Journal of Technology and Design Education	88	14.7	Sullivan and Bers (2019)
8	Experimental evidence on the effect of childhood investments on postsecondary attainment and degree completion	Journal of Policy Analysis and Management	88	7.3	Dynarski et al. (2013)
9	Augmented reality enhanced cognitive engagement: Designing classroom-based collaborative learning activities for young language learners	Educational Technology Research and Development	76	19.0	Wen (2021)
10	Spatial cognition and science achievement: The contribution of intrinsic and extrinsic spatial skills from 7 to 11 years	British Journal of Educational Psychology	74	10.6	Hodgkiss et al. (2018)
11	Think3d!: Training spatial thinking fundamental to stem education	Cognition and Instruction	74	6.2	Taylor and Hutton (2013)

Note: TC: Total citations & TC/Y: Total citations/year

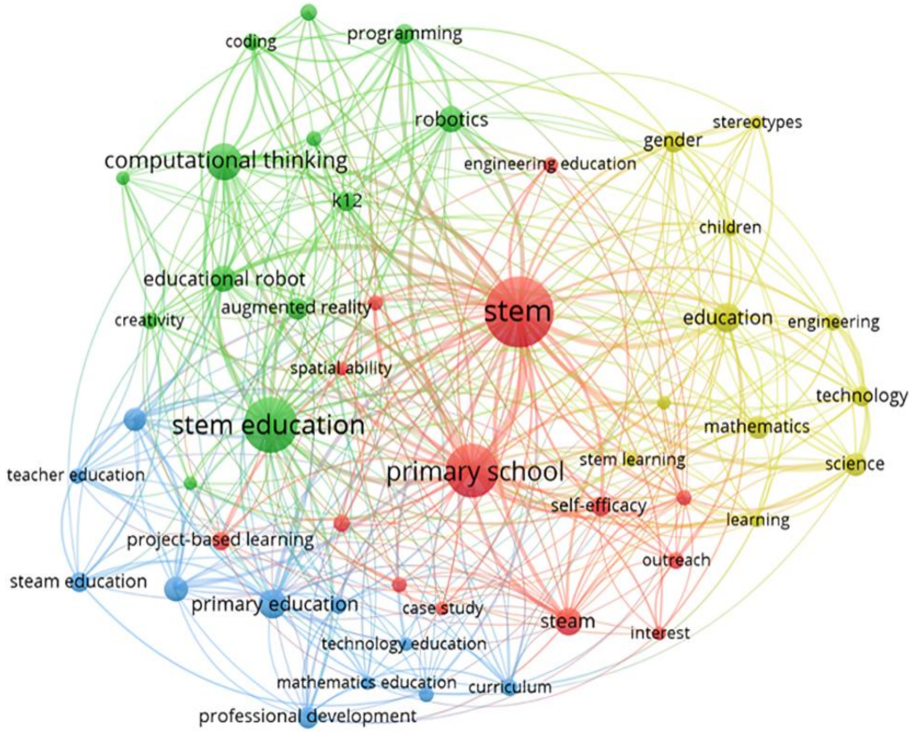

Figure 5. Map of keywords by co-occurrence analysis (Source: Authors' own elaboration, using VOSviewer)

for students to apply mathematical and scientific knowledge by designing and testing paper airplane models. Repenning et al. (2015) employ game design and scientific simulation strategies to enhance computational thinking. Approach et al. (2015) focus on fostering students' self-awareness and crafting skills through storytelling and object-making activities.

The remaining five publications, with citation counts ranging from 74 to 88, focus on three key themes. The first is technology integration in classrooms. For instance, Sullivan and Bers (2019) used robotics to examine students' attitudes and ideas about technology and engineering, while Wen (2021) employed augmented reality to design Hanzi learning games for language education. Both studies highlighted the benefits of technology in increasing student engagement and enhancing learning outcomes, with Wen's study ranking second in TC/year. The second theme pertains to spatial skills and thinking in STEM education. Hodgkiss et al. (2018) and Taylor and Hutton (2013) demonstrated that incorporating spatial skills training into the curriculum significantly improves students' participation and learning in science, contributing to their success in STEM. The third theme is the impact of small classroom settings on student outcomes. Dynarski et al. (2013) provided compelling evidence of the positive effects of early exposure to small classrooms on both short- and long-term academic achievements. This study emphasized the importance of early educational interventions in improving access to higher education, fostering STEM success, and addressing educational inequities.

Keyword Analysis

To identify current research trends and predict future directions, the authors conducted a co-word analysis using VOSviewer. A thesaurus file was employed to enhance the accuracy of the analysis by merging synonyms, abbreviations, and variations in singular/plural forms while eliminating generic or irrelevant terms. **Figure 5** illustrates the results, where each node represents a keyword. The node size reflects the frequency of the keyword in the dataset, while the thickness of the connecting lines represents the strength of the relationships between keywords. The analysis included keywords appearing at least eight times to establish meaningful connections. This resulted in 49 keywords from a total of 2,040 author keywords.

The primary focus of the red cluster is on integrating STEM into curricula and fostering self-directed learning skills at the primary education level. Key keywords in this cluster include "self-efficacy," "attitude," "motivation," "project-based learning," "engineering education," "case study," "interest," "outreach," and "spatial ability." Related studies emphasize the importance of designing age-appropriate STEM and STEAM curricula for elementary students (Capobianco et al., 2011; Jeong et al., 2023; Lyublinskaya & Sheehan, 2019). These efforts aim to enhance students' motivation, interest, attitudes, self-learning skills, and spatial abilities (Hodgkiss et al., 2018; Lennon-Maslin et al., 2023; Vongkulluksn et al., 2018). Commonly adopted methods include project-based learning and case studies within outreach environments, particularly in

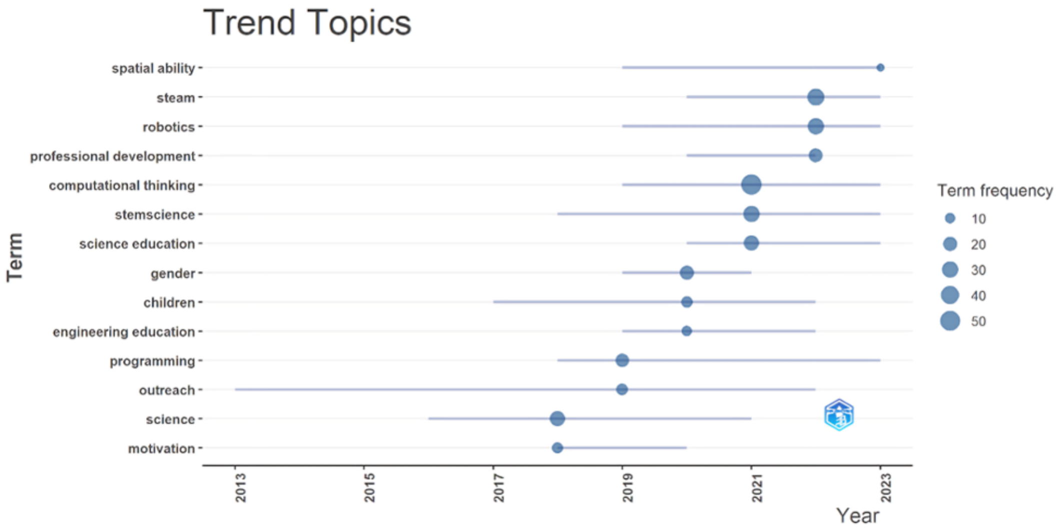

Figure 6. The trend topics of the publication collection on authors' keywords, period 2013-2023 (Source: Authors' own elaboration, using Biblioshiny)

engineering education (Approach et al., 2015; Zhong et al., 2024).

The green cluster highlights the potential of technology in STEM education. Key keywords in this cluster include "augmented reality," "computational thinking," "computer science education," "creativity," "educational robot," "robotics," "programming," "problem-solving," "game-based learning," and "coding." Studies within this trend leverage emerging technologies such as augmented reality, robotics, and coding, along with teaching methods like game-based learning, to develop students' computational thinking, programming, problem-solving, and creativity skills (Repenning et al., 2015; Tanalol et al., 2023; Wen, 2021).

The blue cluster focuses on curriculum development and teacher training, particularly enhancing teacher professional development. Studies recommend improving teachers' competencies in technology education, mathematics education, and science education through well-structured courses tailored to teachers' needs (Pappa et al., 2024), organizing long-term STEM professional development programs (Lie et al., 2019), and training interdisciplinary communication skills (Lin et al., 2022). Additionally, some studies suggest that preparing teachers for STEM instruction should begin during their time as pre-service students in teacher education programs (Martínez-Borreguero et al., 2022; Ting et al., 2020). Moreover, teachers' attitudes toward STEM have been identified as a critical factor influencing the effectiveness of STEM teaching (Martínez-Borreguero et al., 2018).

The yellow cluster addresses gender and social biases in STEM, negatively affecting girls' motivation, confidence, and participation in STEM education (Archer et al., 2013; Ghazy et al., 2019). These challenges contribute to less representation of women in STEM careers (Master et al., 2017). Several strategies have been proposed to mitigate these effects and encourage greater participation among female students. These include boosting girls' confidence and interest through experiences such as programming robots with smartphones (Master et al., 2017), organizing learning activities involving parental participation (Krause et al., 2007), and implementing early educational interventions to address gender stereotypes that form at a young age (Dynarski et al., 2013).

To explore research trends further, the authors analyzed author keywords from 2013 to 2023. **Figure 6** illustrates the yearly trends by identifying keywords associated with the most significant developments. Only keywords appearing in at least eight publications per year were included, with the top three keywords per year representing the identified trends. Keywords unrelated to research trends were excluded.

The information in **Figure 6** reveals that keywords related to STEM in primary schools have been increasingly prevalent over the past six years, particularly between 2019 and 2022. Representative keywords include: 2018: "science," "motivation". 2019: "programming," "outreach". 2020: "gender," "children," "engineering education". 2021: "science education," "STEM science," "computational thinking". 2022: "STEAM," "professional development," "robotics" 2023: "spatial ability." These keywords align with the four primary research trends discussed above.

In addition to keyword trends, the authors used a thematic map (**Figure 7**) to visualize the development and focus of research trends based on keyword distribution. The map categorizes themes into four groups based on their development and relevance: Motor themes: Represent rapidly growing and highly impactful research trends (Cobo et al., 2011; Pham-Duc et al., 2022). These include expanding STEM into STEAM, focusing on teacher professional development,

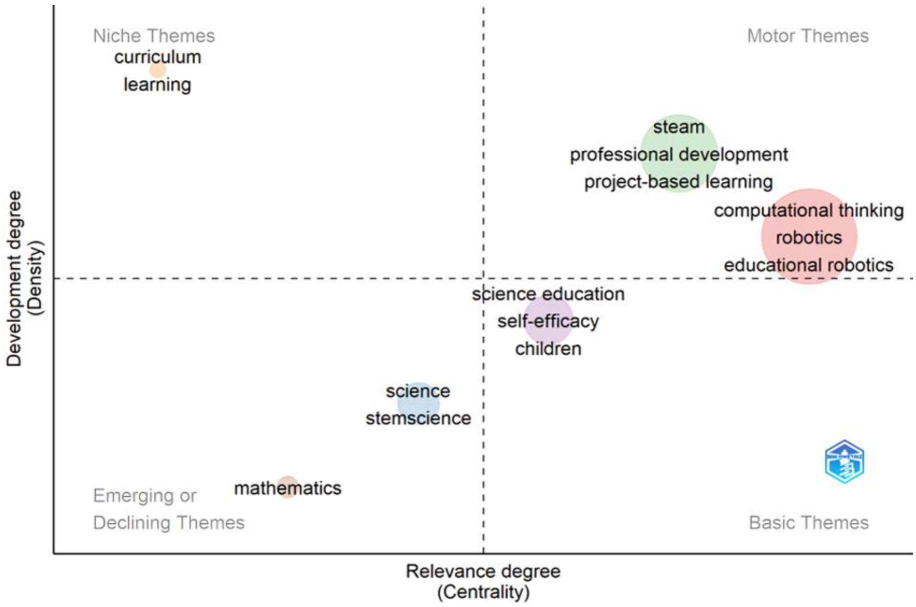

Figure 7. Thematic map of research directions related to STEM in primary school (Source: Authors' own elaboration, using Biblioshiny)

integrating new technologies, and using robotics to enhance computational thinking in students. Niche themes: Represent important but less developed areas. Keywords like "curriculum" and "learning" reflect efforts to create tailored learning programs. Emerging or Declining themes: Represent topics gaining traction or losing relevance. For example, research on "mathematics" as a standalone subject has declined, with a growing emphasis on integrating mathematics into broader STEM contexts (Goos et al., 2023). Basic themes: Represent foundational but underdeveloped areas. These include designing science education programs tailored to elementary school characteristics and capabilities. The thematic map highlights that the current priority in STEM education research is to advance STEAM initiatives emphasize teacher professional development, integrate innovative technologies, and refine teaching methodologies in robotics to foster computational thinking in students. While some niche and foundational themes remain underdeveloped, these areas offer opportunities for future exploration and growth.

DISCUSSION

STEM education has become a focal point of educational research in recent years. Comprehensive reviews on STEM education, especially with diverse learner groups, have been undertaken by several scholars. For elementary students, the study by Tuyet et al. (2024) was limited to the Southeast Asian context. This research, however, represents the first comprehensive bibliometric analysis of all studies on STEM in primary schools indexed in the Scopus database. Based on the study's scope, 967 publications were analyzed. The results reveal that while STEM-related publications became more common after 2011, there has been a significant surge since 2015, particularly during 2019-2023 (see **Figure 2**). The year 2019 marked a dramatic increase in publications compared to earlier periods, driven by global policy initiatives prioritizing STEM education.

Key policies include a vision for innovation in STEM education in the USA (Yoh et al., 2021), the national STEM school education strategy 2016-2026 in Australia (Murphy et al., 2019), the STEM executive consultation (STEMEC) project in Malaysia (Liew & Teoh, 2022), and the UK's DfE (department for education) strategy 2015-2020 (Wang, 2021). Additionally, initiatives by UNESCO, LEGO Education, and the Intel Teach Program have promoted STEM education worldwide by providing STEM education toolkits and supporting teachers. These efforts have expanded STEM adoption, yielding positive educational results, sparking learning enthusiasm, and equipping students with the necessary skills to address 21st century challenges (Huang et al., 2023).

As of December 1, 2024, 115 publications had been indexed for the year. However, this number does not represent the complete output for 2024, as data were collected before the year's end. Additionally, Scopus indexing often lags behind the actual publication dates (Björk & Solomon, 2013), making it premature to assess the trends for 2024 fully.

The USA is the most prominent contributor to the collection, with the most publications and citations (**Table 2**). This aligns with findings from Tuyet et al. (2024) regarding STEM education in Asia. The USA's leading role is unsurprising, given its pioneering efforts in STEM fields (Atkinson & Mayo, 2010). The US government has prioritized STEM as a national strategy, supported by significant investments. For example, the "Educate to Innovate" campaign launched in 2009 allocated $200 million to fund STEM education (Yoh et al., 2021). In 2010, the USA established a STEM Education Committee comprising 14 agencies to develop a national STEM education strategy (Granovskiy, 2018). Organizations such as the US Department of Education, the National Science Foundation, and the Smithsonian Institution have built infrastructure, provided learning resources, and supported teachers and students through various funding programs to execute this strategy. It is estimated that 105-252 STEM activities are conducted annually across states, with budgets ranging from $2.8 billion to $3.4 billion. Nearly half of these funds are allocated to implementing STEM in K12 curricula (Gonzalez & Kuenzi, 2013). In 2018, a five-year plan was introduced to ensure lifelong access to STEM education for all citizens, with an annual funding of $200 million (Yoh et al., 2021). This national ecosystem for STEM education underscores its importance across all education levels, including primary schools, as noted by the National Research Council (Granovskiy, 2018).

Asia's contributions, mainly from Indonesia and China, also stand out in the dataset. Indonesia ranks second in the number of publications and citations. In this country, the Kurikulum 2013 (K-13) replaced the previous curriculum, integrating STEM into the national curriculum as a mandatory component starting in elementary education. This initiative aims to equip students with creative thinking, problem-solving skills, and the ability to apply knowledge in real-world contexts from an early age (Oktavia et al., 2018). Several programs support STEM development in Indonesia, such as the Merdeka Belajar–Kampus Merdeka policy to support STEM teaching, partnerships with the US Global Development Lab for STEM model development (Sofyan et al., 2021), and teacher training through the INSTEM projects (Nugroho et al., 2019).

In China, the Ministry of Education formally recognized STEM education at the primary level in 2017, with its integration into the national curriculum (Lyu et al., 2022). Subsequent initiatives, such as the national STEM action plan and China STEM education 2029, aim to make China a global leader in STEM education by 2029 (Zhan et al., 2021). STEM research in China receives significant support from organizations like the National Natural Science Foundation of China, the Tencent Foundation, and the Huawei Education Initiative. These efforts have significantly advanced STEM education, equipping students in Indonesia, China, and other countries with essential skills to meet future global challenges.

The growing interest of researchers in STEM in primary school is reflected in the collaborative nature of publications. In addition to domestic collaboration, many studies involve international partnerships, with the USA, China, Australia, and Indonesia serving as key hubs for intercontinental cooperation (**Figure 3**).

The USA stands out for its number of publications and citations and its prominent authors. Jeon, M. and Quek, F., from the USA, rank first regarding the number of publications and citations, respectively (**Table 4**). Leading the list of affiliations with the most publications is Universitas Pendidikan Indonesia from Indonesia (**Table 3**). Notably, this institution manages two Scopus-indexed journals with Q1 and Q2 rankings, the Indonesian Journal of Science and Technology and the ASEAN Journal of Science and Engineering. This underscores its strength in advancing research and fostering international publications.

The findings in **Table 5** and **Figure 4** indicate that the quality of publications on STEM in primary schools has improved over the years. Among the 160 sources contributing to this body of work, 35 are dedicated exclusively to STEM education. The most prolific source is AACE, with 54 publications. AACE is the annual conference and exposition organized by the American Society for Engineering Education (ASEE). Although access to conference proceedings are not as widely accessed as journals, and researchers generally prioritize journals due to their higher research weight than conference proceedings in many fields (González-Albo & Bordons, 2011; Linde et al., 2011), 54 publications in AACE have garnered 186 citations, including 61 citations for the influential work of Faber et al. (2013). This demonstrates the global interest and impact of research on STEM in primary schools.

The top 11 most-cited publications on STEM in primary schools focus on three key areas: The role of STEM in developing students' skills, thinking, and career orientations. Factors influencing student learning outcomes in STEM education. Applications for technology in STEM education (**Table 6**). These themes align with analyses by Jamali et al. (2023), Zhan et al. (2022), and Giang et al. (2024), who explored bibliometric trends in STEM education broadly.

Keyword analysis identifies four primary research trends in STEM in primary school: Integrating STEM into curricula and fostering self-directed learning at the elementary level; exploring technological potential in STEM education, such as augmented reality, robotics, and computational thinking; program development and teacher training, focusing on professional development and interdisciplinary teaching competencies; and gender and social biases in STEM, addressing barriers to girls' participation and engagement. These findings share similarities with the global bibliometric analysis of STEM education by Zhan et al. (2022), particularly regarding integrating technology and teacher professional development. However, a key distinction in research on elementary students lies in emphasizing practical STEM implementation in curricula and addressing gender and social biases. In contrast, broader STEM education studies focus on long-term strategies such as equity in education and student career pathways.

Research trends in STEM education vary across educational levels. The preschool level focuses on the relationship between STEM achievement and school readiness in young children (Bui et al., 2024). Research trends at the secondary school level are less defined and often overlap, reflecting a mix of themes and priorities (Le Thi Thu et al., 2021). For K12 students, the emphasis shifts to improving academic performance and learning outcomes (Khalil et al., 2024). At the university level, the focus moves to the impact of STEM education on students' employability and career prospects (Zeng et al., 2024). This shows how STEM is applied to learners with different cognitive levels and learning goals.

Research trends also differ regionally. For primary school students in Southeast Asia, studies primarily address challenges related to teacher competency, infrastructure limitations, and socioeconomic factors affecting STEM education in this region (Tuyet et al., 2024). These differences underscore the need for tailored strategies to effectively address the unique needs of different educational levels and areas. These are also issues Samara (2025) and Info (2025) highlighted in their surveys on the perspectives and attitudes of primary school teachers in Greece toward STEM education. Such differences offer detailed insights into the factors influencing STEM education and reflect the economic conditions and educational development strategies specific to each region.

CONCLUSION

This study provides a comprehensive overview of research on the topic of STEM in primary schools from 2004 to 2024. The bibliometric analysis of 967 publications retrieved from the Scopus database reveals a significant increase in publications in recent years, particularly since 2019. This surge can be attributed to policies and strategies promoting STEM education in countries with substantial contributions to the collection, such as the USA, Indonesia, Australia, and China, as well as strong support from international organizations. The most prolific source of publications on STEM in primary schools is not journals but conference proceedings, focusing on engineering education and the application of technology in teaching. While access to conference proceedings is often more limited than journals, AACE stands out as the leading source in terms of the total number of articles and citations. Furthermore, the quality of publications in this field has improved significantly, demonstrated by the growing share of Q1 and Q2 sources. This reflects the increasing attention of researchers to STEM in primary schools.

Four primary research trends in STEM in primary schools have been identified and compared with trends in studies on other educational levels and regions. In addition to common themes, such as adopting new technologies, professional development for teachers, and curriculum development, research on primary school students emphasizes the practical implementation of STEM education and addressing gender and social biases. The top 11 most-cited publications also reflect these trends, underscoring the wide-ranging interest in this area. The findings of this study present a global picture of research on STEM in primary schools. These results provide valuable insights for researchers and serve as a foundation for policymakers, educators, and stakeholders to implement STEM education programs effectively. With the rapid advancement of digital technologies in education, future research should explore emerging technologies, interdisciplinary approaches, and strategies for implementing STEM education more broadly and comprehensively. In addition, in-depth studies are needed to assess STEM education's long-term impacts and outcomes on primary school students. Furthermore, strengthening international collaboration and promoting global STEM initiatives are essential strategies for sustaining progress in this field.

Limitations

This study has several limitations stemming from the data source and tools used. By relying solely on data from the Scopus database, the study may have overlooked significant documents indexed in other databases (Singh et al., 2021). Additionally, the inherent delay in Scopus indexing impacts the comprehensiveness of the analysis, as it may not fully capture the most recent studies (Björk & Solomon, 2013). Another limitation lies in the language restriction applied to the collected publications. Many vital studies written in languages other than English were excluded from this analysis. The tools employed in this research, primarily Bibliometrix and VOSviewer, are designed to facilitate quantitative analysis and provide generalized results. While they are effective for identifying trends and relationships, these tools do not delve into the specific nuances of individual topics. Consequently, some aspects of the research may lack depth. Furthermore, the reliance on total citation counts for many analyses introduces potential bias due to differences in publication timeframes, sources, and subject areas. These factors may skew the representation of influence across the collected publications.

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VNTT: conceptualization and design, writing – original draft, writing – review & editing; **PHT:** conceptualization and design, resources, data curation, formal analysis, writing – review & editing, . All authors agreed with the results and conclusions.

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