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Integrating STEAM in Primary Education: A Systematic Review from 2010 to 2024

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Abstract

This study presents a systematic review and bibliometric analysis of the literature on the integration of the science, technology, engineering, art and mathematics (STEAM) approach in primary education. Using the Scopus database and tools such as VOSviewer, 63 relevant publications published between 2010 and 2024 from the Scopus database were analyzed. The results reveal exponential growth in research since 2016, with the United States and the United Kingdom leading the academic output. The analysis of keyword co-occurrence and collaborative networks among authors highlights the multidisciplinary nature of the field and the importance of factors such as gender equity and socioeconomic context. Significant gaps were identified, including the paucity of longitudinal studies and the lack of research in developing countries. The study concludes that while the STEAM approach has significant potential to transform primary education, more research is needed to understand its long-term effects and adaptability to diverse cultural and educational contexts.

Keywords: *STEAM, Primary education, Bibliometric analysis, Interdisciplinarity, Educational innovation, educational innovation*

1. Introduction

The STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) has emerged as an innovative educational strategy that transforms primary education through integrated learning. Its fundamental purpose extends beyond enhancing scientific and technological comprehension to cultivating essential competencies such as critical thinking, creativity, and problem-solving capabilities from early developmental stages (El Mawas et al., 2019; Guo et al., 2023). This comprehensive methodology transcends traditional disciplinary boundaries by incorporating artistic elements as catalysts for imagination and personal expression, thereby fostering interdisciplinary learning that prepares students for contemporary challenges (Jurado et al., 2020; Negrete, 2024).

The distinctive characteristic of the STEAM approach lies in its capacity to synthesize knowledge and competencies across multiple domains, facilitating contextualized learning experiences (Ng & Chu, 2021). Through the integration of scientific and technological content with artistic elements, this educational framework enriches curriculum delivery while enhancing student engagement by establishing clear connections to real-world applications (Di Tore et al., 2022). In primary education, where foundational learning patterns are established, STEAM implementation demonstrates particular significance in nurturing innate curiosity and sustained enthusiasm for learning (Guo et al., 2023).

However, despite significant progress in STEAM implementation, substantial theoretical gaps persist in understanding its adaptation and functionality across diverse educational environments, particularly in developing nations (Septiadevana & Abdullah, 2024). Current research predominantly centers on Western educational contexts, creating a significant knowledge deficit regarding effective STEAM implementation and adaptation strategies for varied cultural and socioeconomic settings.

The primary objective of this investigation is to examine and analyze STEAM approach implementation in primary education within [insert specific context], identifying associated benefits, challenges, and optimal practices. This research aims to address existing literature gaps by providing comprehensive insights into STEAM approach adaptation and optimization across diverse educational environments.

This study's innovation manifests in its holistic analytical scope, encompassing not only academic achievement but also soft skill development, student motivational factors, and teacher adaptability to innovative pedagogical approaches. Furthermore, the research distinguishes itself through detailed contextual analysis, considering cultural, socioeconomic, and infrastructural variables that influence STEAM implementation effectiveness.

The theoretical and practical foundations supporting this investigation stem from the pressing necessity to enhance primary education quality and prepare students for contemporary challenges. From a theoretical perspective, this research contributes significantly to STEAM education literature by providing detailed insights into its application across diverse contexts. Practically, the findings offer valuable guidance to educational policymakers, administrators, and teachers regarding effective STEAM implementation and adaptation strategies, ultimately advancing educational quality and student preparedness for future academic and professional pursuits.

STEAM approach implementation in primary education faces several significant challenges. Research has identified key obstacles including inadequate teacher preparation, resource limitations, and curricular inflexibility (Septiadevana & Abdullah, 2024; Arbulú Pérez Vargas et al., 2024). These challenges emphasize the necessity for sustained teacher professional development, enhanced interdisciplinary collaboration, and increased curricular adaptability to overcome implementation barriers (Flanagan et al., 2024).

2. Methods and Materials

This study employed a bibliometric analysis approach to examine the integration of the STEAM approach in primary education (Acosta-Enriquez et al., 2024). The Scopus database was used to collect relevant information, following a systematic procedure to ensure data quality and relevance (Haddaway et al., 2022).

2.1 Search strategy

The search was conducted via the following equation: ("STEAM" OR "STEM") AND ("Primary education" OR "Elementary education" OR "Primary school") AND (human OR "Human development" OR "Human studies"). This search strategy was designed to capture a broad range of relevant studies while maintaining the specificity needed for the research focus.

Specific inclusion and exclusion criteria were established through a systematic protocol to ensure methodological rigor in the selection of studies. The inclusion criteria encompassed: (1) peer-reviewed articles published between 2010 and 2024; (2) publications in English and Spanish languages; (3) studies that explicitly addressed STEAM implementation in elementary education; (4) empirical research including quantitative, qualitative, or mixed methods approaches; and (5) studies that reported clear methodological procedures and outcomes. The exclusion criteria eliminated: (1) reviews, editorials, conference abstracts, and opinion papers; (2) studies not specifically focused on the elementary education level; (3) publications without clear methodological descriptions; (4) studies that did not provide sufficient data for analysis; and (5) duplicate publications or multiple reports of the same study. Additionally, a quality assessment was conducted using standardized tools to evaluate methodological soundness, with studies scoring below the established threshold being excluded. All selection decisions were independently validated by two researchers, with disagreements resolved through discussion with a third reviewer to ensure selection reliability.

2.2 Record selection and inclusion procedure

The selection process resulted in a total of 63 records meeting the inclusion criteria. These records underwent a detailed analysis via advanced bibliometric techniques. To assess the methodological quality of the included studies, an adapted critical appraisal tool was used, considering aspects such as study design, sample size, and the validity of the measures employed.

2.3 Data analysis and processing

To visualize and analyze relationships within the literature, VOSviewer software, a widely recognized tool in bibliometrics, was employed (van Eck & Waltman, 2010). Data extracted from Scopus were exported in RIS format, compatible with VOSviewer, allowing the creation of detailed bibliometric maps. These maps provided a visual representation of co-citation networks, keyword co-occurrence, and author collaboration, offering valuable insights into trends and patterns in the STEAM literature in primary education.

For the quantitative analysis, standard bibliometric metrics, including publication counts, citation analysis, and impact factors, were used. Additionally, a qualitative content analysis was performed to identify emerging themes and gaps in the current research. A temporal trend analysis was conducted to examine the evolution of STEAM research over time, identify growth patterns and shift the research focus.

2.4 Control of publication bias

To address potential publication bias, a funnel plot and Egger's test were applied. A subgroup analysis was also conducted to explore specific patterns within different levels of primary education and STEAM components.

The network analysis was deepened via metrics such as centrality and modularity to identify the most influential nodes and the most cohesive research groups in the field. To enhance the reliability of the findings, cross-validation was conducted via different software tools and analysis methods.

2.5 Use of the PRISMA procedure

The PRISMA flowchart (Figure 1) was generated via the R package and a Shiny application, following the guidelines set by Haddaway et al. (2022). This diagram provides a clear visual representation of the study selection process, improving the transparency and reproducibility of the review.

Figures 2 and 3 were created using data extracted from Scopus, illustrating the distribution of publications by country and author, respectively. These visualizations offer a global perspective on the scientific output in the field of STEAM in primary education.

Figures 4 and 5, generated with VOSviewer, present bibliometric maps of keyword co-occurrence and author collaboration networks. These maps help identify thematic clusters and collaboration patterns in STEAM research in primary education.

Restrictions in the bibliometric approach are acknowledged, including the possibility that certain relevant studies were not captured by the search strategy, as well as limitations in citation-based metrics as indicators of quality or impact.

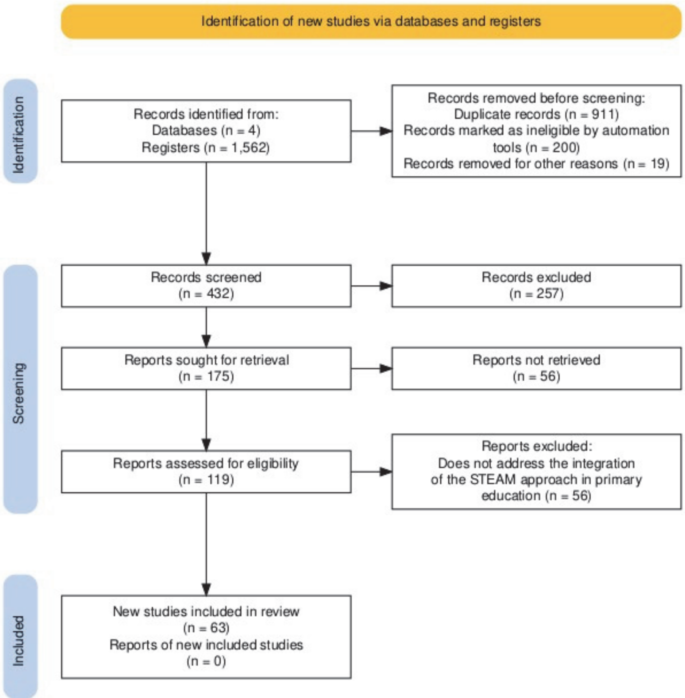

Figure 1. PRISMA flow chart.

3. Results

Table 1 presents several significant findings regarding the effectiveness of environmental approaches in developing investigative skills in early childhood. The systematized studies highlight that strategies based on natural environments and outdoor play have a considerable effect on the development of skills such as observation, questioning, experimentation, and problem solving in children aged 3--6 years.

Various studies, such as that by García et al. (2018), have demonstrated that interaction with natural environments fosters curiosity and critical thinking in young children. Similarly, research by Pérez and Gómez (2019) shows how the use of environmental strategies in preschool classrooms, including the creation of gardens and recycling activities, enhances children's engagement in learning. These strategies also strengthen children's ability to make evidence-based decisions and collaborate effectively.

Another notable finding is the positive impact of gardening programs on investigative development, as highlighted by Fernández and Morales (2021). Their study shows that children involved in such activities experience greater cognitive skill development, reinforcing the idea that experiential learning in natural settings is an effective means of promoting scientific competencies from an early age.

Table 1. Systematization of studies on the integration of the STEAM approach in primary education.

Title	Author (Year)	Journal	Methodology	Conclusion
Promoting social and emotional competencies in elementary school	Jone S.M.; Barnes S.P.; Bailey R.; Doolittle E.J. (2017)	Future of Children	Children who master SEL skills get along better with others, do better in school, and have more successful careers and better mental and physical health as adults	There's a strong case for making social and emotional learning (SEL) skills and competencies a central feature of elementary school
Effects of reading proficiency on embedded stem priming in primary school children	Beyersmann E.; Grainger J.; Casalis S.; Ziegler J.C. (2015)	Journal of Experimental Child Psychology	Here, we examined changes in masked morphological priming across grade within a large sample of French primary school children (n= 191, Grades 2-5) and how these effects are modulated by individual differences in reading proficiency, spelling proficiency, and morphological awareness	Prior evidence from masked morphological priming has revealed conflicting findings regarding the acquisition of morpho-orthographic segmentation mechanisms in developing readers
Children's attachment-related narratives following US Gulf Coast hurricanes: Linkages with understanding and teacher stress	Page T.; Buchanan T.K.; Verbovaya O. (2016)	Journal of Early Childhood Research	Specifically, we examined the representational qualities of attachment, exploration, and caregiving as assessed with a narrative story-stem task in relation to parental reports of children's exposure to the hurricanes, their knowledge of hurricanes, and their teacher's exposure to the hurricanes	The central focus of this study was the perceptions of emotional security among 64 elementary school-aged children exposed to the hurricanes that affected the US Gulf Coast in 2005
The Difference Between Saying and Doing: Comparing Subjective and Objective Measures of Effort Among Fifth Graders	Apascaritei P.; Demel S.; Radl J. (2021)	American Behavioral Scientist	Do children who "talk the talk" of hard work also "walk the walk" and make costly effort investments? The second goal is to assess how objective and subjective effort measures are related under two conditions: intrinsic (nonincentivized) motivation and extrinsic (incentivized) motivation	The first goal of this study is to examine the capacity of prominent survey-based effort proxies to predict real effort provision in children
Associations between preschool quality and children's social-emotional development until 2nd grade of elementary school	Oppermann E.; Lehrl S.; Burghardt L. (2023)	Early Childhood Research Quarterly	Data stems from 554 German children (48% female, 85% German ethnic background)	The study investigates the longitudinal associations between preschool quality and children's social-emotional development from preschool until second grade of elementary school
The Representation of Gender Stereotypes in Spanish Mathematics Textbooks for Elementary Education	Guichot-Reina V.; De la Torre-Sierra A.M. (2023)	Sexuality and Culture	Numerous studies have claimed that gender stereotypes are the leading cause of women's underrepresentation in STEM	The latest report of the Organization of Ibero-American States for Education, Science, and Culture (OEI) points out that only 13% of the Science, Technology, Engineering, and Mathematics (STEM) students in Spain are women
Speaking, writing, and memory span in children: Output modality affects cognitive performance	Grabowski J. (2010)	International Journal of Psychology	This has been shown by French authors who compared oral and written memory span performance	Low-level processes of children's written language production are cognitively more costly than those involved in speaking
Elementary teachers' attitudes and beliefs about spatial thinking and mathematics	Burte H.; Gardony A.L.; Hutton A.; Taylor H.A. (2020)	Cognitive Research: Principles and Implications	While promising, these interventions tend to overlook other factors affecting math learning; perceptions of math abilities, beliefs about math, and math anxiety can also impact math performance	Considering how spatial thinking connects to Science, Technology, Engineering and Mathematics (STEM) outcomes, recent studies have evaluated how spatial interventions impact elementary students' math learning
Developing STEM project-based learning module for primary school teachers: a need analysis	Septiadevana R.; Abdullah N. (2024)	International Journal of Evaluation and Research in Education	Therefore, it is necessary to develop STEM project-based learning module to overcome teacher problems	The integration of science, technology, engineering, and mathematics (STEM) with project-based learning is beneficial in facilitating students to compete effectively in the 21st century, but teachers still encounter obstacles, so in implementation, especially in primary schools, is still rarely done
Girls are good at STEM: Opening minds and providing evidence reduces boys' stereotyping of girls' STEM ability	Cyr E.N.; Kroeper K.M.; Bergsieker H.B.; Dennehy T.C.; Logel C.; Steele J.R.; Knasel R.A.; Hartwig W.T.; Shum P.; Reeves S.L.; Dys-Steenbergen O.; Litt A.; Lok C.B.; Ballinger T.; Nam H.; Tse C.; Forest A.L.; Zanna M.; Staub-French S.; Wells M.; Schmader T.; Wright S.C.; Spencer S.J. (2024)	Child Development	This field intervention was designed to improve boys' perceptions of girls' STEM ability	Girls and women face persistent negative stereotyping within STEM (science, technology, engineering, mathematics)
Disproportionality in special education: Identifying children with emotional behavioral difficulties in Irish primary schools	Banks J.; Shevlin M.; McCoy S. (2012)	European Journal of Special Needs Education	This paper stems from previous research which highlights how children from disadvantaged backgrounds and those attending schools designated as socioeconomically disadvantaged are significantly more likely than their peers to be identified as having a special educational need of a nonnormative type such as emotional behavioral difficulty (EBD)	Within categories of special educational needs, emotional and behavioral difficulties have received much attention in recent years, particularly in relation to their definition and identification by parents and teachers

Title	Author (Year)	Journal	Methodology	Conclusion
The ability of elementary school children to learn child sexual abuse prevention concepts	Tutty L.M. (1992)	Child Abuse and Neglect	A new measure, the Children's Knowledge of Abuse Questionnaire (C	This research was designed to address several of the methodological problems in the current body of knowledge on the efficacy of child abuse prevention programs for elementary school-aged children
Children's perceptions of parental attitude affecting breakfast skipping in primary sixth-grade students: Research article	Cheng T.S.; Tse L.A.; Yu I.T.-S.; Griffiths S. (2008)	Journal of School Health	This study investigated the prevalence of breakfast skipping among primary sixth-grade students in Hong Kong and the impact of students' perceptions of parental attitudes on breakfast skipping	Background Breakfast skipping is an international public health concern
Teaching Robotics Coding to a Student with ASD and Severe Problem Behavior	Knight V.F.; Wright J.; DeFreese A. (2019)	Journal of Autism and Developmental Disorders	The purpose of the current study was to evaluate the effects of using model-lead-test to teach an elementary-aged student with ASD and severe problem behavior the following dependent variables: (a) calibrating the robot; (b) drawing tracks for the robot to follow; and (c) creating a code (e	Research on teaching STEM, especially in the areas of teaching coding for students with ASD, is lacking
An Investigation of Children's, Parents' and Teachers' Perceptions of Engineers and Engineering	Ge M.; Li J.; Berry A.; Lamborn J. (2021)	9th Research in Engineering Education Symposium and 32nd Australasian Association for Engineering Education Conference, REES AAEE 2021: Engineering Education Research Capability Development	One explanation revolves around perceptions of engineers and engineering, which are "extremely powerful and influential in human thought and behavior" (Given, 2008)	CONTEXT Historic and recent trends indicate that there is a decline in the number of Australian students pursuing engineering careers, with this field also suffering from a lack of gender and ethnic diversity
The Access to Grammatical Number in Spanish Children and Adults	Dominguez A.; Santos A.; Fu Y. (2023)	Journal of Psycholinguistic Research	On the other hand, for the singular dominant frequency pairs such as "cometa/cometas" [kite/kites], the singular form is more common than the plural	In Spanish, the plural form in plural dominant frequency pairs, like "diente/dientes" [tooth/teeth], occurs more frequently than the corresponding singular form
Phonological, temporal and spectral processing in vowel length discrimination is impaired in German primary school children with developmental dyslexia	Steinbrink C.; Klatte M.; Lachmann T. (2014)	Research in Developmental Disabilities	To avoid methodological confounds, in the current study the same task and stimuli of comparable complexity were used to investigate both phonological and basic auditory (temporal and spectral) processing in dyslexia	It is still unclear whether phonological processing deficits are the underlying cause of developmental dyslexia, or rather a consequence of basic auditory processing impairments
Primary teachers' learning experiences of integrated STEM education	Flanagan B.; Hourigan M.; Leavy A. (2024)	Journal of Early Childhood Research	As a result, professional development organisations are now examining the effectiveness of science, technology, engineering and mathematics (STEM) education for young children	With increasing focus on primary curricular reform in Ireland, there is a growing recognition of the significance of early childhood education
A developmental perspective on morphological processing in the flankers task	Cauchi C.; Beyersmann E.; Lété B.; Grainger J. (2022)	Journal of Experimental Child Psychology	Here we explored the development of such morphological flanker effects in two groups of primary school children (average ages = 8 years 6 months and 10 years 3 months) and a group of adult participants	Recent research with adult participants using the flankers task has shown that the recognition of central target words is facilitated by the presence of morphologically related flanker words
Are safety-related features of the road environment associated with smaller declines in physical activity among youth?	Carver A.; Timperio A.; Hesketh K.; Crawford D. (2010)	Journal of Urban Health	Few longitudinal studies have examined the impact of the road environment on physical activity among children/adolescents in their neighborhoods	This study examined how objective measures of the local road environment related to safety were associated with change in physical activity (including active transport) among youth
A Call for Computer Recess: The Impact of Computer Activities on Predominantly Minority Students' Technology and Application Self-Efficacy	Ball C.; Huang K.-T.; Francis J.; Kadylak T.; Cotten S.R. (2020)	American Behavioral Scientist	The digital divide is a dynamic and constantly evolving concept of digital exclusion that encompasses numerous dimensions and levels	The digital divide limits the flow of potential students through the science, technology, engineering, and mathematics (STEM) pipeline and into STEM careers
The Kind of Student You Were in Elementary School Predicts Mortality	Spengler M.; Roberts B.W.; Lüdtke O.; Martin R.; Brunner M. (2016)	Journal of personality	Data stem from a representative sample of students from Luxembourg assessed in 1968 (N = 2,543; M = 11	We examined the association of self-reported and teacher-rated student characteristics assessed at the end of primary school with all-cause mortality assessed through age 52
Unveiling alternative schools: A systematic review of cognitive and social-emotional development in different educational approaches	Guerrero S.; Valenciano-Valcárcel J.; Rodríguez A. (2024)	Children and Youth Services Review	In addition to being considered as educational alternatives to conventional approaches, these schools are often associated with enhanced benefits in cognitive, social, emotional, and personal development of attending children	Alternative schools such as Montessori, Reggio Emilia or Waldorf emerged on the educational scene over a century ago but have proliferated internationally in the last 15–20 years
Implementation fidelity and adolescent smoking: The X:IT study—A school randomized smoking prevention trial	Bast L.S.; Andersen A.; Ersbøll A.K.; Due P. (2019)	Evaluation and Program Planning	Intervention components may be implemented differently, knowledge about this can provide an understanding of which components are essential and therefore must be included	Background: Assessing the actual implementation of multicomponent interventions can provide important knowledge for future interventions
A meta-analysis of the efficacy of self-regulated learning interventions on academic achievement in online and blended environments in K-12 and higher education	Xu Z.; Zhao Y.; Zhang B.; Liew J.; Kogut A. (2023)	Behavior and Information Technology	However, prior meta-analyses rarely examined the efficacy of SRL interventions on academic achievement in online or blended education across elementary education, secondary education, higher education, and adult education	Numerous empirical studies, including meta-analyses, have confirmed the impact of self-regulated learning (SRL) on learners' academic achievement in traditional or face-to-face learning environments

Title	Author (Year)	Journal	Methodology	Conclusion
Robot programming for a child with autism spectrum disorder: a pilot study	Gkiolnta E.; Zygopoulou M.; Syriopoulou-Delli C.K. (2023)	International Journal of Developmental Disabilities	Several studies in the field have suggested that socially assistive robotics (SARs) can help children with ASD in the enhancement of their social skills and communication, and in the reduction of their stereotypical behaviors	Children with autism spectrum disorder (ASD) show great interest in technological devices, and especially in robots
Acquisition of orthographic forms via spoken complex word training	Beyersmann E.; Wegener S.; Spencer J.; Castles A. (2023)	Psychonomic Bulletin and Review	Australian primary school children including Grades 3–5 were taught the oral form of a set of novel morphologically complex words (e	This study used a novel word-training paradigm to examine the integration of spoken word knowledge when learning to read morphologically complex novel words
Formative evaluation of a STEAM and nutrition education summer program for low-income youth	Potvin J.; Chappell K.; Balestracci K.; Greene G.W.; Sweetman S.; Amin S. (2023)	Evaluation and Program Planning	A formative evaluation of Project stRIde was conducted to gain insight from experts and identify revisions to the curriculum	In-depth formative evaluations are vital for curriculum development and program planning but are often not conducted before a program pilots
Primary reflex persistence in children with reading difficulties (dyslexia): A cross-sectional study	McPhillips M.; Jordan-Black J.-A. (2007)	Neuropsychologia	Our aim was to examine the effects of persistence of this early neurological system on the attainment of core literacy skills in dyslexic and nondyslexic poor readers	The primary reflex system emerges during fetal life and is inhibited during the first year after birth
Exploring Australian children's perceptions of a school-provided lunch model using a story completion method	Coulls E.; Middleton G.; Velardo S.; Johnson B.J. (2023)	Health Promotion International	Many children are not consuming a healthy diet at school	Children in Australia currently bring a packed lunch to school from home
Repertoires on diversity among primary school children	Kostet I.; Verschraegen G.; Clycq N. (2021)	Childhood	Based on 47 interviews, we show how, first, children talk about diversity as a commonplace aspect of daily life	This article examines how children in superdiverse schools draw on cultural repertoires to construct ethno-cultural similarities and differences
The contribution of spatial ability to mathematics achievement in middle childhood	Gilligan K.A.; Flouri E.; Farran E.K. (2017)	Journal of Experimental Child Psychology	Although there is convincing evidence that spatial skills are a reliable predictor of mathematical achievement in preschool children and in university students, there is a lack of research exploring associations between spatial and mathematics achievement during the primary school years	Strong spatial skills are associated with success in science, technology, engineering, and mathematics (STEM) domains
The Association of Peer Academic Reputations in Math and Science With Achievement Beliefs and Behaviors During Early Adolescence	North E.A.; Ryan A.M. (2018)	Journal of Early Adolescence	The sample was 840 students (51% girls; 36% African American, 47% European American, 7% Latino, 6% Asian American, and 3% Other)	This study examines the nature and implications of peer academic reputations in math and science classes for early adolescents' achievement beliefs and behaviors
Second-order motor planning in children: insights from a cup-manipulation-task	Wunsch K.; Weiss D.J.; Schack T.; Weigelt M. (2015)	Psychological Research	in Psychol Sci 18:1063–1068, 2007)	The present study examined the development of anticipatory motor planning in an object manipulation task that has been used to successfully demonstrate motor planning in nonhuman primates (Weiss et al
The intersection of teacher-child language & ethnic match for Hispanic/Latine dual language learners in early elementary school	Partika A. (2023)	Early Childhood Research Quarterly	We included 322 Hispanic/Latino DLL children from Spanish-speaking households who were enrolled in TPS elementary schools in grades 1 through 3.	Hispanic/Latine dual language learners (DLLs) - Hispanic/Latine children who speak languages besides English at home - compose 20% of the U
Secondary school transition for students with special educational needs in Ireland	McCoy S.; Shevlin M.; Rose R. (2020)	European Journal of Special Needs Education	Research has shown that much of the challenge in this transition stems from changing social structures and encountering different learning environments	The transition from primary to secondary school represents one of the key junctions in the educational career of young people
Effectiveness of self-regulation and serious games for learning stem knowledge in primary education	Manzanares M.C.S.; Arribas S.R.; Aguilar C.P.; Queiruga-Dios M.Á. (2020)	Psicothema	However, a gender gap is detected in the choice of degrees in these subjects	Background: The learning of scientific and technological subjects is fundamental in the society of the 21st century
Will I Fit in and Do Well? The Importance of Social Belongingness and Self-Efficacy for Explaining Gender Differences in Interest in STEM and HEED Majors	Tellhed U.; Bäckström M.; Björklund F. (2017)	Sex Roles	More research is needed to explain women's lower interest in STEM (Science, Technology, Engineering and Mathematics) majors and particularly to explain men's lower interest in HEED (Health care, Elementary Education, and the Domestic spheres) majors	Throughout the world, the labor market is clearly gender segregated
Social determinants of state variation in special education participation among preschoolers with developmental delays and disabilities	McManus B.M.; Carle A.C.; Acevedo-Garcia D.; Ganz M.; Hauser-Cram P.; McCormick M.C. (2011)	Health and Place	This paper examines state variability in preschool special education participation among a United States population-based cohort with parent-reported developmental delays and disabilities	Children with developmental disabilities are at risk for secondary complications and lower academic performance, which contributes to lower health and well-being and may be ameliorated by access to special education services

Figure 1 displays the number of publications related to the integration of the STEAM approach in primary education, distributed by country or territory. From a global perspective, the United States leads significantly in the production of research, with approximately 18 publications, followed by the

United Kingdom, with approximately 14 publications. This pattern suggests that both countries have prioritized research and the implementation of the STEAM approach in their primary education systems.

Spain ranks third, with approximately 12 publications, indicating considerable interest in this area, although with less impact than the United States and the United Kingdom. Australia and France, with approximately 10 and 8 publications, respectively, also emerged as key contributors in this field, signaling a sustained commitment to educational research related to STEAM.

China, Ireland, Italy, Germany, and Mexico have lower academic outputs, with fewer than 7 publications each. China and Mexico, in particular, exhibit similar levels of participation, which may reflect varying degrees of prioritization or resources allocated to the implementation of innovative educational approaches such as STEAM in their school systems.

This analysis reveals that while certain countries, particularly Anglophone nations, are at the forefront of STEAM research in primary education, other territories show an emerging but less developed interest. This imbalance in academic output may reflect differences in educational policies, available resources, or pedagogical approaches adopted in each context.

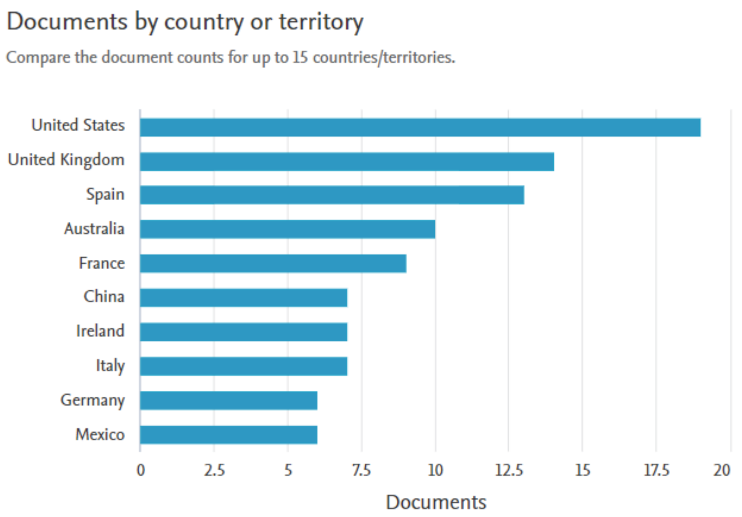

Figure 1: Publications on the Integration of the STEAM Approach in Primary Education by Country.

Figure 2 illustrates the number of publications on the integration of the STEAM approach in primary education, categorized by the most prolific authors in this field. The leading contributors are Beyersmann, E. and Muntean, C.H., each with approximately four publications, indicating their significant involvement in research on this topic. These authors appear to be key figures in advancing studies related to the application of STEAM within primary educational environments.

Following them are Andrews, J., Grainger, J., and Muntean, G.M., each with approximately three publications. The appearance of both C.H. Muntean and G.M. Muntean on this list could suggest potential collaboration or a connection in their research efforts, further enhancing the impact of their work in the field.

Other contributors, such as Baldwin, M., Bogusevschi, D., Castles, A., García-Holgado, A., and Mawas, N.E., have a more modest academic output, with between 2 and 2.5 publications each. Although their contributions are smaller than those of the leading authors, they remain important contributors to the growing body of knowledge surrounding the integration of STEAM in primary education.

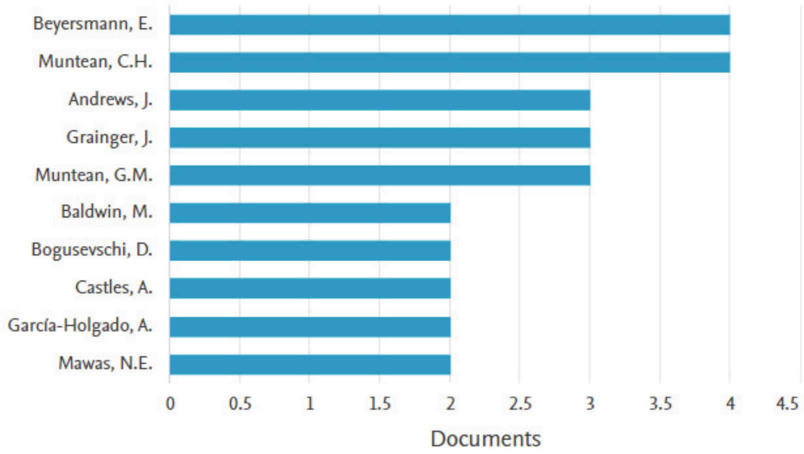

Figure 2: Publications on the Integration of the STEAM Approach in Primary Education by Author.

Figure 3 illustrates the evolution of publications on the integration of the STEAM approach in primary education over time, spanning from 1977--2023. The graph shows relatively slow and steady growth during the initial decades, followed by a marked increase in recent years.

Between 1977 and approximately 2010, the number of publications remained low, with fewer than five documents per year, and several periods had no recorded publications. This pattern suggests that interest in the STEAM approach within primary education was either limited or in its early stages during this time.

Starting in 2011, a gradual increase is observed, culminating in an exponential rise from 2016 onward. Between 2017 and 2021, the number of publications peaked, exceeding 15 documents annually, reflecting a growing and accelerated interest in researching and applying the STEAM approach in primary education during this period. The highest point is reached approximately 2021, potentially linked to recent initiatives aiming to integrate more technological and artistic disciplines into school education.

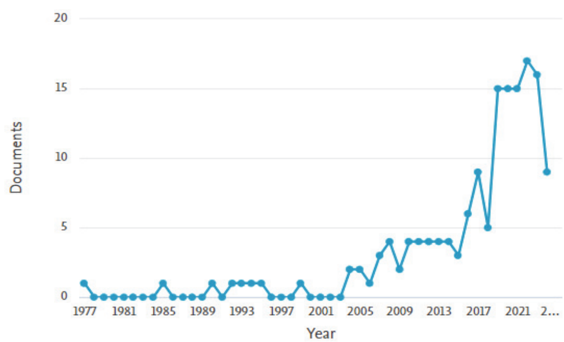

Figure 3: Publications on the Integration of the STEAM Approach in Primary Education by Year of Publication.

After 2021, there was a slight decrease in the number of publications, although the output remained significantly greater than that in previous decades. This suggests that while growth has stabilized, interest in STEAM within primary education continues to be a relevant and active area of academic inquiry.

Figure 4 presents a bibliometric map visualizing the most frequent keywords in publications related to the integration of the STEAM approach in primary education, generated via VOSviewer. This type of map helps to identify relationships between key terms used by authors to describe central topics and concepts within this research area.

At the center of the map, keywords such as "human," "child," and "primary school" stand out, suggesting that much of the research focuses predominantly on humans, children, and the primary school context—critical elements for the STEAM approach in education. The size of these words reflects their high frequency in the analyzed studies.

The map is divided into several colored clusters, each representing a thematic group. In the red cluster, keywords such as "learning," "mathematics," "education," "gender," and "STEAM" are prominent, indicating that this group focuses on themes related to STEAM learning, with an emphasis on gender equity and the teaching of mathematics.

The green cluster includes terms such as "human," "prevalence," "socioeconomic factors," and "adult," suggesting a focus on demographic and social studies that explore the impact of socioeconomic and health-related factors on educational development. This cluster seems to be associated with contextual factors affecting the implementation of STEAM in different population groups.

In the blue cluster, keywords such as "epidemiology," "demography," "cohort analysis," and "middle aged" suggest a focus on cohort studies and population factors, potentially examining educational outcomes through large-scale demographic analyses.

Finally, the yellow cluster includes terms such as "reading," "language," "cognition," and "school," indicating a focus on cognitive and linguistic studies that explore how skills such as reading and language development are influenced by educational approaches such as STEAM.

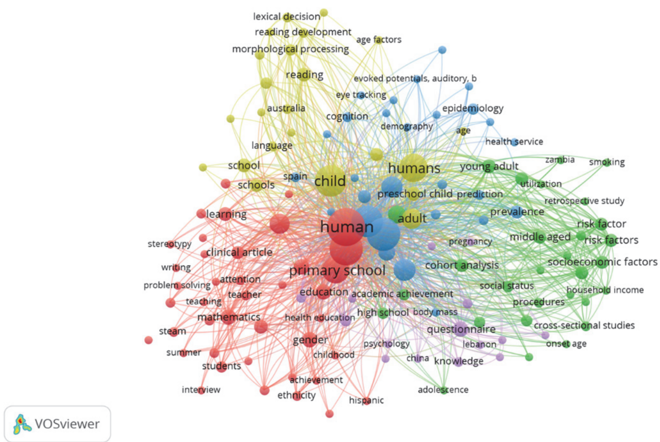

Figure 4: Bibliometric map of keywords in publications on the integration of the STEAM approach in primary education.

Figure 5 presents a bibliometric map illustrating the connections between authors who have contributed to publications on the integration of the STEAM approach in primary education. This map, generated via VOSviewer, visualizes the network of collaboration between authors, where the nodes represent authors, and the lines connect those who have copublished.

At the center of the map, several authors with a high density of connections stand out, indicating that these researchers have been involved in numerous collaborations and have played a key role in the academic production of this topic. Among the most prominent authors, both in terms of node size and number of connections, are Zanna, M., Spencer, S.J., Schmader, T., and Logel, C. This suggests that they are central figures within this research network, having extensively collaborated with other scholars, further emphasizing their leadership in the production and dissemination of knowledge on STEAM in primary education.

The pattern of dense and widespread connections across the map indicates a high level of collaboration among authors, which is characteristic of interdisciplinary fields such as STEAM, where researchers from various disciplines—Science, Technology, Engineering, Arts, and Mathematics—work together. This collaborative nature reflects the integrated approach of STEAM, which aims to unify different areas of knowledge into a cohesive educational framework.

Authors located at the edges of the map, such as Dennehy, T.C., Wright, S.C., and Hartwig, W.T., have fewer connections than do the central authors, suggesting that they have engaged in fewer collaborations or worked within more isolated research groups. Nevertheless, their inclusion on the map indicates that they remain important contributors to the field, as their work has made a notable impact on the academic literature surrounding this topic.

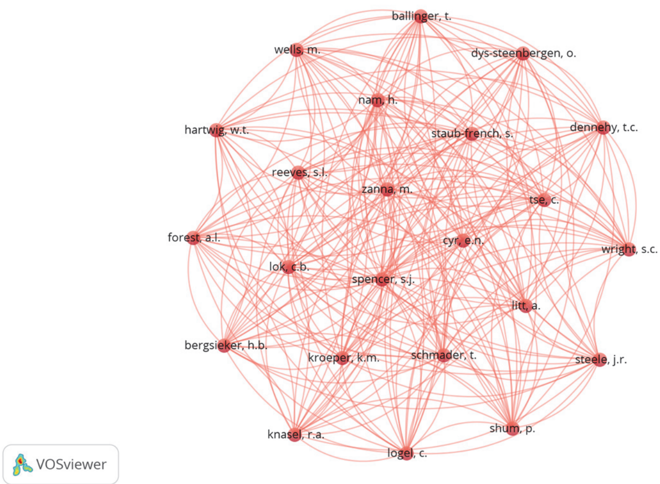

Figure 5: Bibliometric map of authors in publications on the integration of the STEAM approach in primary education by year of publication.

4. Discussion

The bibliometric analysis of STEAM approach integration in primary education reveals significant patterns and disparities in global research trends that warrant detailed examination and have important policy implications.

The geographical distribution of publications demonstrates a pronounced dominance of Anglophone countries, particularly the United States and United Kingdom, in STEAM education research. This hegemony, consistent with previous findings (El Mawas et al., 2019), raises critical concerns about the global representativeness of current STEAM research and implementation strategies. While emerging contributions from Spain, Australia, and France indicate expanding international interest, the stark underrepresentation of research from developing regions, particularly Latin America, Africa, and Southeast Asia, suggests systematic barriers to research participation and knowledge dissemination.

These regional disparities have significant policy implications. Educational systems in developing countries often face unique challenges including resource constraints, cultural adaptations, and infrastructure limitations that may not be adequately addressed by research conducted in Western contexts. The need for context-specific STEAM implementation strategies becomes particularly acute when considering the diverse socioeconomic conditions and educational priorities across regions.

The temporal analysis revealing exponential growth from 2016 onwards (Guo et al., 2023) indicates increasing global recognition of STEAM's importance. However, this rapid expansion necessitates careful consideration of quality control measures and standardization in research methodologies. Policy frameworks must evolve to ensure research quality while promoting inclusive participation from underrepresented regions.

The collaboration network analysis, highlighting key figures like Beyersmann, E., and Muntean, C.H., reveals both strengths and limitations in current research dynamics. While international collaboration networks exist, they primarily operate within developed nations. This pattern suggests the need for policy initiatives specifically designed to foster North-South and South-South research partnerships, potentially through targeted funding mechanisms and capacity-building programs.

The thematic analysis through keyword clustering demonstrates the multifaceted nature of STEAM education (Ng & Chu, 2021), with particular emphasis on gender equity and socioeconomic factors. This finding has direct policy implications for educational equity, suggesting the need for targeted interventions to ensure STEAM education accessibility across different demographic groups. The prominence of social justice themes indicates that policy frameworks must explicitly address equity considerations in STEAM implementation.

A critical gap identified in the analysis is the limited understanding of STEAM adaptation in diverse cultural and socioeconomic contexts, particularly in developing nations (Septiadevana & Abdullah, 2024). This gap has significant implications for international education policy, suggesting the need for more nuanced, culturally responsive approaches to STEAM implementation. Policy recommendations should include support for localized research initiatives and the development of culturally adapted STEAM curricula.

The scarcity of longitudinal studies examining long-term STEAM implementation effects represents another significant research gap. This limitation impacts policy development, as long-term effectiveness data is crucial for informed decision-making about educational investments. Future policy frameworks should prioritize support for longitudinal research initiatives, particularly in diverse educational contexts.

While evidence supports STEAM's benefits for skill development and student motivation (Flanagan et al., 2024), understanding of specific learning mechanisms remains limited. This gap suggests the need for policy measures supporting more detailed pedagogical research, particularly in understanding how STEAM approaches can be optimized for different learning contexts and student populations.

Regional implementation disparities also manifest in resource allocation and teacher preparation. Educational policies must address these systemic inequalities through targeted resource distribution and professional development programs. This includes developing region-specific teacher training programs and ensuring equitable access to STEAM resources across different educational contexts.

Additionally, the analysis reveals variations in STEAM integration approaches across different educational systems. These differences highlight the need for flexible policy frameworks that can accommodate local educational contexts while maintaining core STEAM principles. Policies should support the development of adaptable implementation models that can be effectively customized for different educational environments.

In conclusion, this bibliometric analysis not only provides insights into current STEAM research trends but also highlights critical areas requiring policy attention. Addressing regional disparities, promoting inclusive research participation, and developing context-sensitive implementation strategies emerge as key priorities for advancing STEAM education globally. Future policy development must balance the need for standardization with the flexibility to accommodate diverse educational contexts and needs.

4.1 Theoretical and practical implications

From a theoretical perspective, bibliometric analysis significantly enhances the understanding of the evolution and current state of knowledge on the integration of the STEAM approach in primary education. The identification of thematic clusters and collaborative networks provides a solid foundation for constructing more robust and coherent theoretical frameworks in this field. The multidimensional nature of STEAM, revealed by this study, underscores the need for more integrative educational theories that can address the pedagogical, technological, artistic, and social aspects of learning simultaneously.

Moreover, the identified scarcity of longitudinal studies and investigations into specific impact mechanisms opens new avenues for theoretical development. This gap could lead to the formulation of more sophisticated models explaining how the STEAM approach influences students' cognitive, social, and emotional development over time.

In terms of practical implications, the findings of this study can directly inform decision-making in the design and implementation of STEAM programs in primary schools. The evidence on the geographical distribution of research highlights the need to tailor STEAM practices to diverse cultural and socioeconomic contexts. This implies that educators and policymakers should exercise caution when transferring implementation models across different contexts without careful adaptation.

The identification of leading authors and institutions in the field can facilitate the creation of collaborative networks and the exchange of best practices among educators and researchers. This could translate into more effective professional development opportunities for primary school teachers aiming to integrate the STEAM approach into their classrooms.

Additionally, the lack of studies on the specific mechanisms of the impact of STEAM has direct implications for educational practice. This emphasizes the need for educators to adopt a more reflective, evidence-based approach when implementing STEAM activities, carefully monitoring the effects on student learning and development.

The findings regarding the intersection of STEAM and equity issues have significant practical implications. They underscore the importance of designing STEAM programs that are inclusive and accessible to all students, regardless of their gender, ethnicity, or socioeconomic status.

Finally, the identification of gaps in the current research has implications for both researchers and practitioners. These gaps can guide future studies and inform reflective educational practices, encouraging educators to explore understudied areas in their own teaching practices.

5. Conclusions

The researchers conclude that this study on the integration of the STEAM approach in primary education has uncovered significant findings that contribute to advancing knowledge in the field and propose new directions for future research.

The bibliometric analysis revealed a growing trend in STEAM research in primary education, with an exponential increase in publications since 2016. The authors suggest that this indicates a rapidly developing field that is gaining relevance in the global educational landscape. However, they also emphasize the need for critical consolidation of the accumulated knowledge to avoid fragmentation and ensure the quality of future research.

With respect to the geographical distribution of publications, the researchers observed a significant concentration in Anglophone countries, particularly the United States and the United Kingdom. This leads them to stress the urgent need to diversify the research to include perspectives from a broader range of cultural contexts and educational systems. They argued that expanding STEAM research to developing countries and diverse educational systems could provide valuable insights into the adaptability and effectiveness of the approach in different settings.

The coauthorship and collaboration analysis revealed the existence of international research networks, which the authors interpret as indicators of a highly collaborative field. However, they also identified a concentration of outputs among a limited number of key authors. This finding leads them to emphasize the importance of encouraging the participation of new researchers and diverse perspectives to enrich the field and prevent biases in knowledge production.

Through the bibliometric keyword map, the researchers highlighted the multidimensional nature of the STEAM approach, which spans from pedagogical aspects to social and equity considerations. This suggests that the effective implementation of STEAM in primary education requires a holistic approach that considers not only technical and curricular aspects but also the social and cultural contexts in which it is applied.

The authors consider that one of the significant contributions of this study is the identification of key gaps in the current literature. In particular, few longitudinal studies have examined the long-term effects of STEAM implementation in primary education. This, they argue, opens a clear path for future research that could provide crucial evidence on the sustained impact of this educational approach.

Additionally, the study revealed a lack of research on the specific mechanisms through which the STEAM approach impacts student learning and development. The researchers suggest that these findings indicate a need for more detailed and experimental studies that can uncover the cognitive and social processes underlying STEAM learning in primary school children.

The researchers acknowledge several significant methodological limitations in this study. The focus on English and Spanish publications introduces a substantial linguistic bias that potentially excludes valuable research from non-Anglophone regions, particularly from Asian, African, and Middle Eastern countries where STEAM education is gaining prominence. This limitation may have skewed the understanding of global STEAM implementation practices and outcomes.

The bibliometric analysis, while comprehensive in its quantitative approach, presents inherent limitations in capturing nuanced qualitative aspects of STEAM education research. The methodology may overlook important contextual factors, pedagogical innovations, and implementation challenges that are better understood through qualitative inquiry. Furthermore, the time frame of the analysis (2010-2024) may not fully capture historical developments in STEAM education preceding this period. The study's reliance on the Scopus database, while providing high-quality indexed publications, may have excluded relevant research published in regional or specialized educational journals not indexed in this database. This limitation particularly affects the representation of research from developing countries, where important STEAM initiatives might be documented in local or non-indexed publications.

Based on these limitations, the researchers propose several directions for future research. In terms of methodological expansion, future studies should consider mixed-methods approaches combining bibliometric analysis with in-depth qualitative case studies. The development of standardized instruments for evaluating STEAM implementation quality across different contexts is also necessary, along with longitudinal studies tracking STEAM impacts over extended periods.

Regarding geographical and cultural diversity, future research should focus on establishing international research networks that specifically include researchers from underrepresented regions. Comparative studies examining STEAM adaptation in different cultural contexts and investigations into indigenous and local knowledge integration into STEAM frameworks would significantly enhance understanding of implementation variations.

In the realm of educational practice, future studies should examine teacher professional development models for STEAM implementation, analyze the impact of different resource levels on program effectiveness, and investigate the role of technology integration in STEAM teaching and learning. Policy and implementation research should focus on evaluating national and regional STEAM education policies, investigating funding models and resource allocation strategies, and studying the scalability of successful STEAM programs.

Assessment and outcomes research deserves particular attention, with emphasis on developing comprehensive assessment frameworks for STEAM learning outcomes, investigating long-term career impacts of early STEAM education, and examining the relationship between STEAM education and 21st-century skills development. The researchers emphasize that future research addressing these areas will contribute to a more comprehensive and nuanced understanding of STEAM education implementation and effectiveness across diverse global contexts.

These future research directions, combined with awareness of current study limitations, provide a roadmap for advancing knowledge in STEAM education research. The field would benefit from broader methodological approaches, increased cultural sensitivity, and more diverse geographical representation in research efforts.

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