

Mapping the Landscape of STEM Education in Primary Schools: A Bibliometric Review and Future Outlook

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Abstract

Numerous issues exist regarding STEM education in elementary schools. These problems include: 1) ignorance of the need to develop curricula that are in line with elementary school students' cognitive development and comprehension; 2) indifference to the dearth of resources for STEM education, the lack of professional development, and the unequal distribution of STEM education resources, particularly in rural and developing nations. The author used the Scopus.com database to conduct a bibliometric study of primary school STEM education-focused articles in order to comprehend the current state of affairs about STEM education in elementary schools. The author used RStudio to analyze 203 of the papers, and a descriptive analytic approach was used to interpret the analysis's findings. The study's findings show that the quantity of publications devoted to the application of STEM in primary education has significantly increased over time. The number of publications devoted to the use of STEM teaching models at the primary school level shows this trend. The degree of development and STEM education literacy at the primary school level is influenced by the curricular policies, the technology resources available, and the instructors' readiness. More research should concentrate on a comprehensive and more integrated strategy with an emphasis on technological and pedagogical advancements in curriculum creation that is pertinent and aligned with 21st Century educational abilities if it is to have a meaningful and relevant impact.

Keywords: Bibliometrics Analysis, Education, Elementary School, Learning, STEM

INTRODUCTION

One of the main priorities now is integrating STEM (science, technology, engineering, and mathematics) methods into the elementary school curriculum. Enhancing STEM literacy is an important consideration in the wake of rapid technological advancements and the increasing need for STEM skills globally (Safiee et al., 2018; Kanaki & Kalogiannakis, 2022). However, the future of elementary education is threatened by a number of important challenges despite the vast potential offered by STEM. Among these is a dearth of knowledge about creating a STEM program that is in line with the cognitive development of children; a lack of resources and training for teachers; and, more specifically in rural and less developed regions, equity in access to STEM programs (Boz, 2023; Mercan et al., 2022; Halliburton et al., 2024; Way et al., 2022). In addition, STEM approaches are often employed independently from the core curriculum, which has no impact on students' learning (Ng & Adnan, 2018; Mateos-Núñez et al., 2020). This is despite the fact that these approaches have been embraced by various institutions of learning. The effects of STEM education have not been extensively studied on students' socio-emotional development, academic performance, and career goals, particularly in elementary education. Thus, STEM education is a solution. However, there are large gaps

between reality and expectations in this field (Margot & Kettler, 2019; Martínez-Borreguero et al., 2022; Bircan & Çalışıcı, 2022; Kanaki & Kalogiannakis, 2022; Ilma et al., 2023).

The importance of this research is based on the need to address this fundamental question in a comprehensive and scientific manner. By conducting a comprehensive examination of the benefits, challenges, and future trends, this research aims to provide useful recommendations for stakeholders to make the most of the implementation of STEM education in elementary schools. This is further supported by the fact that elementary schools are an important initial stage for encouraging students' STEM interests and skills, which can have a substantial effect on their future career choices (Thao et al., 2024; Jaipal-Jamani, 2024). If the quality and availability of STEM education are not improved, then social and economic disparities will widen. There has been a substantial rise in the integration of STEM education into elementary school curricula over the last decade. STEM education was first integrated into university and secondary school curricula. However, current trends show earlier integration (Fernández-Cézar et al., 2020; Safiee et al., 2018; Tuyet et al., 2024). This is because children are naturally curious and eager to engage with challenging concepts by experience and learning (Slim et al., 2022; Lilly et al., 2022; Ng & Adnan, 2018; Meier & Hendel, 2019). In addition, new technologies in education like coding, robotics, and virtual simulation have made it easier for students to learn the content of STEM education (Chiang et al., 2022; Jaipal-Jamani, 2024; Chou, 2018; Lilly et al., 2022; Smyrnova-Trybulska et al., 2016). However, due to the rapid development, there are also inequalities in the application of STEM education. Some schools are performing well, while others are struggling due to a variety of reasons such as lack of funding, unqualified teachers, or unclear curriculum guidelines (Amaaz et al., 2024; Lilly et al., 2022; Martínez-Borreguero et al., 2022; Halliburton et al., 2024; Smyrnova-Trybulska et al., 2016).

Some research has been carried out on the advantages and disadvantages of STEM education in elementary schools. Research carried out between 2014 and 2025 (Lilly et al., 2022; Mafugu et al., 2022; Fernández-Cézar et al., 2020; Siregar et al., 2019; Ow-Yeong et al., 2023; Toma & Greca, 2018) revealed that the integration of STEM subjects can enhance learning among students, especially in mathematics and science subjects. For instance, a study carried out by Kelley & Knowles (2016) revealed that project-based STEM activities led to an increase in student engagement and problem-solving abilities. In a similar study, a meta-analysis carried out by Genek & Küçük (2020) revealed that robotics-based STEM interventions led to an improvement in students' creativity and computational thinking. But problems like unprepared teachers and the inability to integrate STEM activities into the

existing curriculum have been highlighted in other studies (Gul et al., 2023; Nguyen & Tran, 2024; Tresnawati et al., 2021). Furthermore, few studies have investigated the impact of STEM education on students' career goals or its socio-emotional impact (Babarović et al., 2018; Bircan & Çalışıcı, 2022; Çaycı & Örnek, 2019; Toma & Greca, 2018; Mateos-Núñez et al., 2020), although many have focused on cognitive outcomes. While our understanding of STEM education has evolved, several questions remain unaddressed in the current literature. First, there are few longitudinal studies examining the impact of STEM interventions on students' education and careers (Li et al., 2022; Margot & Kettler, 2019; Siregar et al., 2019). Additionally, research shows that STEM programs are successful in local schools that provide educational resources (Ahmad et al., 2024; Gagnier et al., 2023). Third, some research has been done on the collaboration of interdisciplinary teachers in providing STEM curricula that are more integrated (Gao et al., 2020; Tytler et al., 2019; Yahya & Hashim, 2021). In conclusion, further research is necessary to ensure that minority groups, such as women and minority students, are represented in STEM activities (Gagnier et al., 2023).

With the combination of bibliometric analysis and systematic literature review (SLR), this research provides novelty. By doing so, the combination of the two methods also reveals the unanswered patterns, gaps, and research opportunities. This research also provides evidence-based recommendations on how to overcome the difficulties in putting STEM into practice, especially in resource-constrained schools. Moreover, this research highlights the importance of inclusive and sustainable approaches. This bibliometric review specifically addresses the long-term effects of STEM education, including both local and global views. The aim of this bibliometric review is to offer a wider perspective by integrating the findings of previous studies and relevant research topics for future studies. This will greatly help in the policy-making process and practice of STEM education in elementary schools. This review will not only improve academic debates but will also offer useful recommendations for educators, policymakers, and researchers aiming to improve STEM learning outcomes. Therefore, the research questions are presented as follows:

1. What are the key insights from STEM research articles in elementary schools published in Scopus?
2. What are the publication trends in Scopus related to the implementation of STEM in elementary schools?
3. Based on the relevance and development of STEM use in elementary education, what is the thematic position of the topic?

METHOD

Article Selection Process

This study employed bibliometric analysis, which is typically used to identify patterns and trends in scientific publications. This type of analysis is highly effective in providing a comprehensive overview of a field's historical evolution, the relationship between journals and authors, current research patterns and trends, recent research, and potential research gaps within the discipline. The PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) method guided the article selection process. Data were obtained from articles published between 2009 and 2024 in Scopus-indexed journals that discussed the implementation of STEM-based learning. Figure 1 illustrates the article selection process using the PRISMA approach.

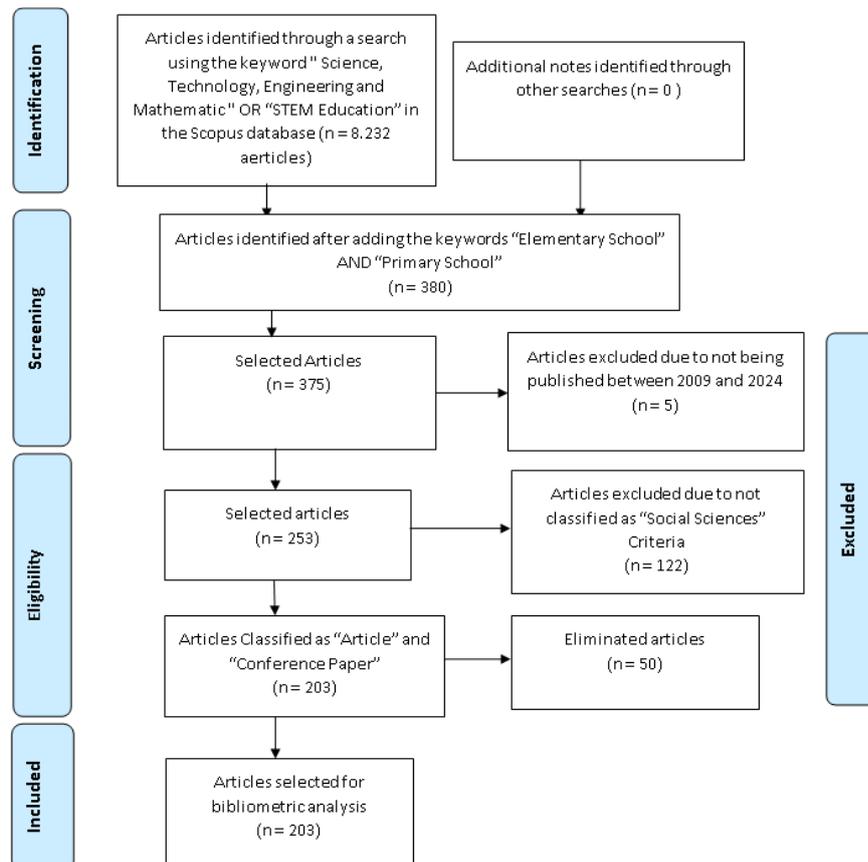


Figure 1. PRISMA Model for Articles Selection

Figure 1 shows the stages of article selection for the analysis dataset. Initially, a broad search was conducted using the keywords "Science, Engineering, Technology, and Mathematics" or "STEM Education" without limiting the publication year or document type, resulting in 8,232 articles. Then, the selection was refined by limiting the publication year from 2009 to 2024, resulting in 375 articles. Next, filtering was performed by selecting the subject

area “Social Sciences”, resulting in 253 articles. Finally, the document type was limited to “Articles” and “Conference Papers,” resulting in a total of 203 articles selected for analysis..

Data Analysis

We conducted a bibliometric study on the application of STEM in elementary school education by examining several key research aspects. First, we examined the number of articles indexed in Scopus related to the application of STEM in elementary school education. Then, we examined the publication trends of these articles from 2009 to 2024. Finally, we examined thematic positions based on relevance and current developments. Biblioshiny, a tool within RStudio, was used to process all data retrieved from the Scopus database. By allowing researchers to import datasets downloaded from Scopus in CSV, RIS, or BibTeX formats, RStudio enables bibliometric data visualization. The researcher can then perform other analyses, such as network analysis, theme analysis, and train identification, and easily generate visual representations and reports. Finally, descriptive analysis and interpretation are done on the RStudio results.

RESULTS AND DISCUSSION

Key Information on STEM Education in Primary Schools

Research on the use of STEM education in primary schools is expected to grow significantly between 2009 and 2024, according to the Key Information section (see Table 1). The growth and evolution of STEM teaching approaches in elementary school curricula over the last decade has been subtly apparent. Since 2010, there has been an increase in interest in STEM education globally, according to Li et al. (2022). This is consistent with the 21st century's demand for abilities like creativity, critical thinking, and teamwork. These skills are essential for a knowledge-based economy and the Fourth Industrial Revolution (Fitrya et al., 2020; Hanif et al., 2019; Micari & Pazos, 2020; Siregar et al., 2019; Yalçın, 2021). Moreover, as Kanaki & Kalogiannakis (2022) and Safiee et al. (2018) have found, there has been a trend in educational policies to include early STEM literacy to ensure economic competitiveness. This paper not only illustrates the development of research on STEM education over the years but also illustrates the trend in educational policies to increasingly include STEM research in the primary education system.

Table 1. Key Information on Research Articles Published in Scopus-Indexed Journals (2009–2024)

Description	Results
Main Information About Data	
Timespan	2009:2024
Sources (Journals, Books, etc)	135
Documents	203
Annual Growth Rate %	24.07
Document Average Age	4.42
Average citations per doc	10.75
References	9071
Document Contents	
Keywords Plus (ID)	491
Author's Keywords (DE)	625
Authors	
Authors	626
Authors of single-authored docs	19
Authors Collaboration	
Single-authored docs	19
Co-Authors per Doc	3.29
International co-authorships %	15.27
Document Types	
Article	163
Conference paper	40

The number of sources employed in this study was comprised of 135 books, journals, and scientific publications, as indicated in Table 1. The above numbers show that the literature on STEM topics in elementary schools is vast and applicable. This is attributed to the fact that this method combines science, technology, engineering, and mathematics into an integrated curriculum, which means that a wide range of sources is important for STEM research (Thao et al., 2024; Estapa & Tank, 2017). Moreover, literature from different fields is commonly employed in STEM education research to create novel and integrated learning programs and approaches. Because an interdisciplinary approach to STEM education requires a variety of theoretical and practical foundations, Honey et al. (2014) argue that using multiple sources is crucial. This study examined 203 documents demonstrating significant academic interest in STEM education in primary schools. This is in line with the findings of English (2017), who argued that there is an increasing number of STEM publications that are being produced as part of a global initiative to enhance STEM literacy from a young age due to the complex skill requirements of the future. The views of Sanders Županec et al. (2022) also support this, as they argued that the interdisciplinary approach to STEM education has led to a substantial amount of research being conducted on innovative approaches to teaching that will satisfy the needs of

students in the digital age. A number of studies have found that STEM education has moved from being a trend to becoming the main focus of elementary education studies to satisfy the needs of students.

With an annual growth rate (AGR) of 24.07%, interest has also shown a tremendous increase. The number of publications focusing on STEM education in elementary schools has been steadily increasing, and this is the reason for the tremendous increase. These results support the claim made by Li et al. (2022) that there is a need to improve STEM skills worldwide in order to produce a workforce that can keep pace with technological developments. Toma & Greca (2018) also claimed that the adoption of educational policies that have begun to include STEM in the national curriculum in many countries is mainly to improve the competitiveness of human resources in the context of globalization. In general, this section of the paper proves the significant increase in the number of studies on the implementation of STEM in primary schools over the past decade. The need for 21st-century skills and educational approaches that incorporate STEM into the primary school curriculum is the key factor that has contributed to the increase in the number of studies (Sari et al., 2024; Toma & Greca, 2018; Boz, 2023; Estapa & Tank, 2017; Khurma et al., 2023; Larkin & Lowrie, 2023; Margot & Kettler, 2019). Many sources point to the interdisciplinary approach that characterizes STEM education, but numerous documents indicate that this topic continues to attract the attention of researchers from various disciplines. Significant yearly increase suggests that STEM education is more than simply a fad and has emerged as a key area of primary education study. According to earlier research, one of the greatest ways to get kids ready for the opportunities and problems of the digital and globalized age is to teach them STEM subjects in elementary school.

STEM Publication Trends in Primary Schools

Although trends vary, from 2009 to 2024, scientific publications on the application of STEM in elementary schools generally increased in the Annual Scientific Production Section (see Figure 2).

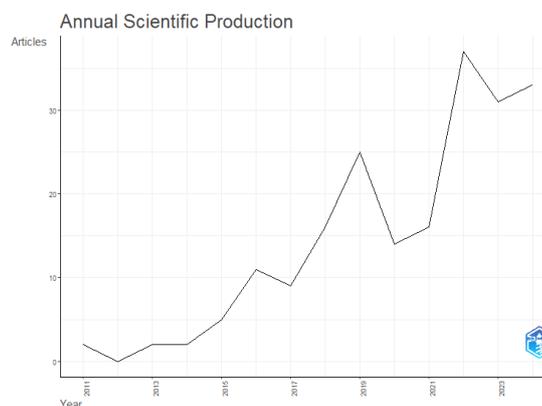


Figure 2. Annual Scientific Production of STEM Research Articles in Primary Schools

From 2009 to 2024, the trend of scientific publications on the implementation of STEM in elementary schools indexed in Scopus is shown in Figure 2. Overall, this graph shows a significant increase in the number of articles published each year. This rise suggests that the topic is receiving more scholarly interest and attention. The first period (2009–2014) had a relatively small and erratic number of publications. This suggests that STEM in elementary school was not yet the main emphasis of educational research at the time. One reason may be the lack of educational policies explicitly integrating STEM into the primary school curriculum, which may have contributed to the low number of publications during this period.

However, this trend began to increase significantly in 2015 and continued to grow through 2019. This surge can be attributed to the growing recognition of integrative approaches to education that emphasize 21st-century skills such as creativity, problem-solving, critical thinking, and collaboration. These skills are core competencies taught in STEM schools. During this period, policies supporting STEM in primary schools have been established by several countries, such as the STEM Education Strategy in Australia and the Next Generation Science Standards (NGSS) in the United States (Lilly et al., 2022). Furthermore, increased access to digital technologies in primary schools has also contributed to increased research on the application of STEM in technology-based learning (Changpetch & Seechaliao, 2019; Chou, 2018; Jaipal-Jamani, 2024; Mafugu et al., 2022; Siregar et al., 2019).

However, the number of publications reduced in 2020. The COVID-19 pandemic resulted in a major disruption to the education sector globally. This might have been the reason for the reduction in the number of publications in 2020. School closures and the swift shift to online education affected research in schools, especially in primary education. In primary education, direct student interaction and the use of physical supports are sometimes incorporated into STEM learning strategies (Fung et al., 2021; Singh-pillay & Naidoo, 2020). This decline was also attributed to the lack of digital infrastructure and teachers' inability to implement STEM learning online (Fung et al., 2021; Singh-pillay & Naidoo, 2020; Tresnawati et al., 2019).

In 2021, the graph shows a sharp increase after this period of decline, peaking at over 30 publications. This surge can be attributed to adaptation to the pandemic situation through the development of more sophisticated hybrid and online learning methods. During this period, research began to focus on the use of digital technologies in STEM education (Ilma et al., 2023). Examples include the use of robotics, augmented reality, and virtual reality to enhance student engagement in distance learning (Chou, 2018; Jaipal-Jamani, 2024). Furthermore, this increase

in publications demonstrates the urgent need to investigate flexible and adaptable learning models to address the challenges facing the education sector worldwide.

The number of publications is still higher than before the pandemic, although there was a further drop in 2022. This shows that there is a great interest in STEM education in elementary schools. Nevertheless, in light of the learning dynamics after the pandemic, there could be shifts in the research methodology and themes. However, by 2023, there was a resurgence, which shows that STEM research has been ongoing and steadily increasing. This could be attributed to the increasing use of technology-based educational strategies and the realization of the significance of STEM literacy in equipping students to meet the challenges of the digital era (Li et al., 2022).

Thematic Map

To identify the most researched topics on the implementation of the STEM curriculum in elementary schools, thematic map analysis was employed (see Figure 3).

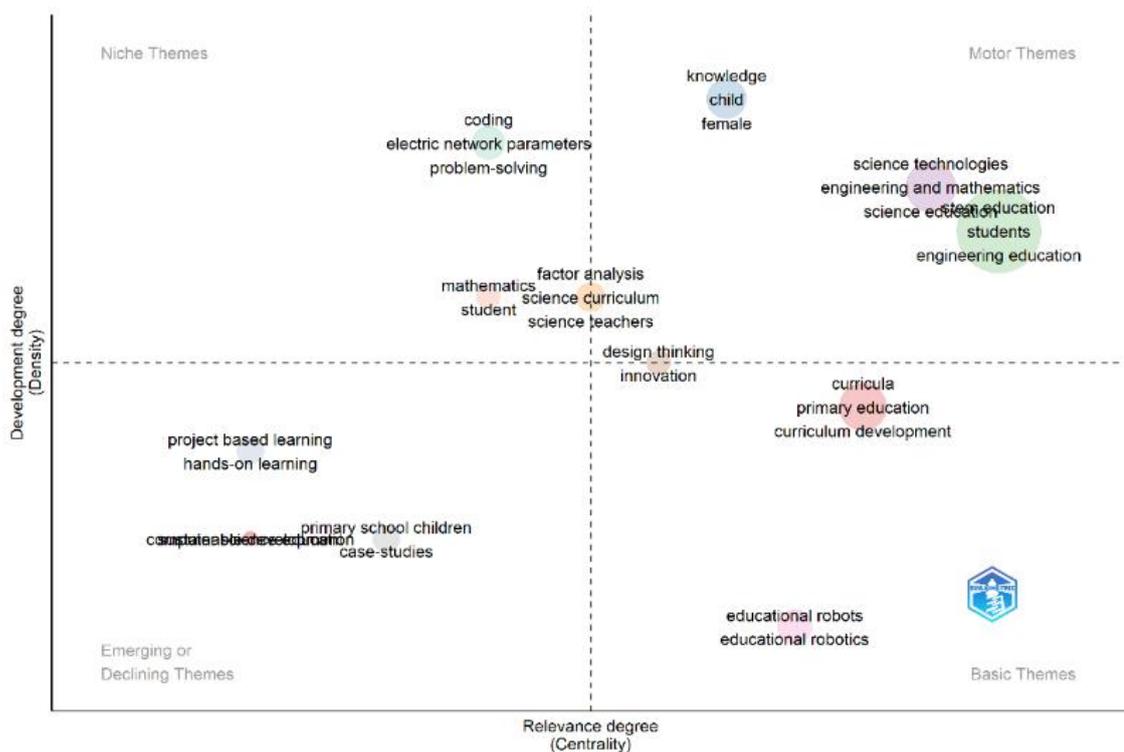


Figure 3. Thematic Map

The themes of research on the implementation of STEM education in elementary schools are categorized based on the dimensions of relevance (relatedness) and density (level of development), as illustrated in Figure 3. Various themes in this field have been developed, are relevant, and have potential for future development, as illustrated in this mapping. The **Motor Themes** quadrant in the upper right corner illustrates themes that are very close and general. This suggests that these themes are very relevant and that there has been extensive

progress in previous research. Mathematics, education, science, and technology are some examples. These themes illustrate the relevance of the integration of science and technology in the elementary school curriculum to enhance STEM literacy from a young age. These results support the study of Kelley & Knowles (2016), which highlighted that students in elementary schools have a better understanding of concepts and the capability to solve more complex problems by integrating science and technology. Furthermore, combining engineering and mathematics in project-based learning has been shown to enhance creativity and scientific reasoning (Diana et al., 2021; Hanif et al., 2019; Safiee et al., 2018). Consequently, the topics discussed in this quadrant are not only highly relevant, but may also be important areas of future research—particularly in terms of pedagogical innovation and curriculum development in primary education.

In contrast, the **Niche Themes** quadrant (top left) includes topics such as troubleshooting, electrical network parameters, and coding. High density counts indicate that these topics have been thoroughly studied, but low centrality counts indicate that STEM education in elementary schools has not yet fully integrated these topics. Elementary schools may lack adequate technology infrastructure, making lessons on technical skills often irrelevant (Fung et al., 2021). Therefore, further research is needed to connect these topics with relevant pedagogical approaches and curricula. This is done to ensure that these topics are accessible to a wider audience in elementary schools. This is despite the topics having been thoroughly studied.

Themes like project-based learning, hands-on learning, case studies, and elementary school children can be categorized under the **Emerging or Declining Themes** quadrant (bottom left). These themes are less significant and less talked about, which indicates that they are irrelevant to the current studies in STEM education or are outdated. However, project-based learning and hands-on learning have been found to be effective in encouraging participation and improving conceptual understanding of STEM education among students. (Costa et al., 2023). The shift in research focus toward more complex technology integration, such as coding and educational robotics, which are considered more relevant for 21st-century skills, may be responsible for the relevance of these themes in the thematic map (Chou, 2018; Jaipal-Jamani, 2024; Temelli et al., 2022). However, hands-on experience with digital technologies and project-based learning still have significant potential to enhance creativity and collaboration (Costa et al., 2023). Therefore, although these topics may seem less important at present, further research on technology integration may restore their popularity in STEM education research in the future.

Meanwhile, topics such as curriculum, elementary education, curriculum development, and educational robotics fall into the **Basic Themes** quadrant (bottom right). While these topics are highly relevant to STEM education research in elementary schools, there is still room for development. The presence and development of curricula in this category suggest that a more comprehensive STEM approach should be incorporated into elementary education curricula immediately. This aligns with Child & May (2018) and Madani & Forawi (2019), who argues that one of the main challenges in STEM implementation is the lack of a holistic and integrated curriculum framework. Additionally, the theme of educational robotics shows great potential for enhancing student engagement and experiential learning (Chou, 2018; Jaipal-Jamani, 2024). However, the low density indicates that, while highly relevant, research on educational robotics is still in an exploratory phase in the context of elementary schools. More studies are needed to connect this topic with specific learning outcomes and strategies for integration into formal curricula for broader adoption.

CONCLUSION

Based on the analysis's findings, it can be said that throughout the past ten years, there has been a significant increase in academic publications about the use of STEM education in primary schools. The shift in the educational paradigm toward the development of 21st-century skills and the growing popularity of interdisciplinary education in the elementary school curriculum have been the main drivers of this increase. The trend unmistakably indicates that there is growing interest in STEM education research, particularly with regard to fostering scientific and technology literacy at an early age, despite some volatility in the number of publications on a yearly basis. This information bolsters the claim that STEM education in elementary schools is crucial for teaching students skills that they can use in the workplace of the future, in addition to helping them grasp science and math. Additionally, it is evident that STEM has expanded quickly in elementary education during the last ten years. This is because of the necessity for students to possess abilities that are applicable to the current world, educational technology advancements, and regulations that increasingly encourage integrated learning strategies. Global events like the COVID-19 epidemic, however, have hampered this advancement and brought attention to the difficulties in continuously delivering STEM education. Teachers are not equipped to incorporate STEM concepts into current curricula because they lack professional development opportunities and training.

Another obstacle to introducing STEM, especially in elementary schools, is a lack of infrastructure and resources, especially in remote or poor institutions. Rigid curricula frequently impede the widespread incorporation of STEM in elementary schools. Science, technology, and

engineering education are examples of highly relevant and developed fields; curriculum development and educational robotics are examples of less developed fields. Additionally, coding and problem-solving are highly studied but less applicable, indicating that integrating cutting-edge technologies in the classroom is difficult.

SUGGESTIONS

Curriculum policies, teacher preparedness, and access to technological resources significantly influence STEM literacy in elementary schools, according to additional analysis. A more holistic and interdisciplinary approach is needed to increase the relevance and impact of future research. This approach must focus beyond technology; it must also focus on pedagogical innovation and curriculum development that aligns with 21st-century skills needs.

REFERENCES

- Ahmad, S. R., Samsudin, M., Adenan, F., Zulkifli, M. F., Rahmawati, E., & Suhaimi, A. I. H. (2024). Evaluation of Academic Enhancement Program for Low-Income Students in Rural Malaysia. *Journal of Technical Education and Training*, 16(2), 241–251. <https://doi.org/10.30880/JTET.2024.16.02.021>
- Amaaz, A., Mouradi, A., Erradi, M., & Allouch, A. (2024). Moroccan pre-service elementary teachers: attitudes toward STEM education and mobile devices. *International Journal of Evaluation and Research in Education*, 13(5), 3270–3283. <https://doi.org/10.11591/ijere.v13i5.28205>
- Babarović, T., Pale, P., & Burušić, J. (2018). The effects of the elementary school STEM intervention program on students' attitudes and interests: The application of propensity score matching technique. *Drustvena Istrazivanja*, 27(4), 583–604. <https://doi.org/10.5559/DI.27.4.01>
- Bircan, M. A., & Çalışıcı, H. (2022). The Effects of STEM Education Activities on Fourth Grade Students' Attitudes to Stem, 21st-Century Skills and Mathematics Success. *Egitim ve Bilim*, 47(211), 87–119. <https://doi.org/10.15390/EB.2022.10710>
- Boz, T. (2023). Teacher Professional Development for STEM Integration in Elementary/Primary Schools: A Systematic Review. *International Electronic Journal of Elementary Education*, 15(5), 371–382. <https://doi.org/10.26822/iejee.2023.306>
- Çaycı, B., & Örnek, G. T. (2019). Effect of Stem-Based Activities Conducted in Science Classes on Various Variables. *Asian Journal of Education and Training*, 5(1), 260–268. <https://doi.org/10.20448/journal.522.2019.51.260.268>
- Changpetch, S., & Seechaliao, T. (2019). The Propose of an Instructional Model Based on STEM Education Approach for Enhancing the Information and Communication Technology Skills for Elementary Students in Thailand. *International Education Studies*, 13(1), 69. <https://doi.org/10.5539/ies.v13n1p69>
- Chiang, F. K., Zhang, Y., Zhu, D., Shang, X., & Jiang, Z. (2022). The Influence of Online STEM Education Camps on Students' Self-Efficacy, Computational Thinking, and Task Value. *Journal of Science Education and Technology*, 31(4), 461–472. <https://doi.org/10.1007/s10956-022-09967-y>

- Child, E., & May, C. (2018). Integrated STEM curriculum : improving educational outcomes for Head Start children Integrated STEM curriculum : improving educational outcomes for Head Start children. *Early Child Development and Care*, 0(0), 1–13. <https://doi.org/10.1080/03004430.2016.1185102>
- Chou, P. N. (2018). Skill Development and Knowledge Acquisition Cultivated by Maker Education: Evidence from Arduino-based Educational Robotics. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(10), 1–15. <https://doi.org/10.29333/ejmste/93483>
- Costa, M. C., Ferreira, C. A. F., & Pinho, H. J. O. (2023). Physics of Sound to Raise Awareness for Sustainable Development Goals in the Context of STEM Hands-On Activities. *Sustainability (Switzerland)*, 15(4). <https://doi.org/10.3390/su15043676>
- Diana, N., Sukma, Y., Baptist, K. J., Subali, B., Mariyam, M., Kaniawati, I., & Sriyati, S. (2021). *The Effect of Project-Based Learning in STEM on Students ' Scientific Reasoning The Effect of Project-Based Learning in STEM on Students ' Scientific Reasoning*. <https://doi.org/10.1088/1742-6596/1835/1/012006>
- English, L. D. (2017). Advancing Elementary and Middle School STEM Education. *International Journal of Science and Mathematics Education* , 15, 5–24. <https://doi.org/https://doi.org/10.1007/s10763-017-9802-x>
- Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: a professional development approach centered on an engineering design challenge. *International Journal of STEM Education*, 4(1). <https://doi.org/10.1186/s40594-017-0058-3>
- Fernández-Cézar, R., Garrido, D., & Solano-Pinto, N. (2020). Do science, technology, engineering and mathematics (STEM) experimentation outreach programs affect attitudes towards mathematics and science? A quasi-experiment in primary education. *Mathematics*, 8(9). <https://doi.org/10.3390/math8091490>
- Fitrya, E., Adlim, M., Gani, A., Syukri, M., & Iqbal, M. (2020). *Developing STEM- Based Student Worksheet to Improve Students ' Creativity and Motivation of Learning Science*. 9, 57–75.
- Fung, E. B., Frey, M. R., Valmont, M. E., Caffey-fleming, D. E., Fraser, M., Williams, J., Killilea, D. W., Bogenmann, E., Livshits, S., & Boone, D. N. (2021). *Success of Distance Learning During 2020 COVID-19 Restrictions : A Report from Five STEM Training Programs for Underrepresented High School and Undergraduate Learners*. 4(3).
- Gagnier, K. M., Holochwost, S. J., Ceren, M., & Fisher, K. R. (2023). Filling a gap: initial evidence for reliable and valid measures of students' self-concept, self-efficacy, and interest in science with elementary students traditionally underrepresented in STEM. *Frontiers in Education*, 8. <https://doi.org/10.3389/feduc.2023.1242876>
- Gao, X., Li, P., & Shen, J. (2020). *Reviewing assessment of student learning in interdisciplinary STEM education*. 4.
- Genek, S. E., & Küçük, Z. D. (2020). Investigation of scientific creativity levels of elementary school students who enrolled in a stem program1-2. *Elementary Education Online*, 19(3), 1715–1728. <https://doi.org/10.17051/ilkonline.2020.734849>

- Gul, K. S., Kirmizigul, A. S., Ates, H., & Garzon, J. (2023). Advantages and Challenges of STEM Education in K-12: Systematic Review and Research Synthesis. *International Journal of Research in Education and Science*, 9(2), 283–307. <https://doi.org/10.46328/ijres.3127>
- Halliburton, P., Georgiou, H., & Nielsen, W. (2024). Makerspaces: Building Confidence in STEM for Primary Preservice Teachers. *Research in Science Education*, 54(4), 573–594. <https://doi.org/10.1007/s11165-024-10153-w>
- Hanif, S., Fany, A., Wijaya, C., & Winarno, N. (2019). *Enhancing Students' Creativity through STEM Project-Based Learning*. 2(December 2018). <https://doi.org/10.17509/jsl.v2i2.13271>
- Honey, M. A., Pearson, G., & Schweingruber, H. (2014). STEM integration in K-12 education: status, prospects, and an agenda for research. In *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. National Academies Press. <https://doi.org/10.17226/18612>
- Ilma, A. Z., Wilujeng, I., Widowati, A., Nurtanto, M., & Kholifah, N. (2023). A Systematic Literature Review of STEM Education in Indonesia (2016-2021): Contribution to Improving Skills in 21st Century Learning. *Pegem Egitim ve Ogretim Dergisi*, 13(2), 134–146. <https://doi.org/10.47750/pegegog.13.02.17>
- Jaipal-Jamani, K. (2024). Educational Robotics and Preservice Teachers: STEM Problem-Solving Skills and Self-Efficacy to Teach. *Canadian Journal of Learning and Technology*, 50(4), 1–21.
- Kanaki, K., & Kalogiannakis, M. (2022). Assessing Algorithmic Thinking Skills in Relation to Age in Early Childhood STEM Education. *Education Sciences*, 12(6). <https://doi.org/10.3390/educsci12060380>
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. In *International Journal of STEM Education* (Vol. 3, Issue 1). Springer. <https://doi.org/10.1186/s40594-016-0046-z>
- Khurma, O. A., Ali, N., & Khine, M. S. (2023). Exploring the impact of 3D printing integration on STEM attitudes in elementary schools. *Contemporary Educational Technology*, 15(4). <https://doi.org/10.30935/cedtech/13568>
- Larkin, K., & Lowrie, T. (2023). Teaching Approaches for STEM Integration in Pre- and Primary School: a Systematic Qualitative Literature Review. *International Journal of Science and Mathematics Education*, 21, 11–39. <https://doi.org/10.1007/s10763-023-10362-1>
- Li, Y., Xiao, Y., Wang, K., Zhang, N., Pang, Y., Wang, R., Qi, C., Yuan, Z., Xu, J., Nite, S. B., & Star, J. R. (2022). A systematic review of high impact empirical studies in STEM education. In *International Journal of STEM Education* (Vol. 9, Issue 1). Springer Science and Business Media Deutschland GmbH. <https://doi.org/10.1186/s40594-022-00389-1>
- Lilly, S., McAlister, A. M., Fick, S. J., Chiu, J. L., & McElhaney, K. W. (2022). Elementary teachers' verbal supports of science and engineering practices in an NGSS-aligned science, engineering, and computational thinking unit. *Journal of Research in Science Teaching*, 59(6), 1035–1064. <https://doi.org/10.1002/tea.21751>

- Madani, R. A., & Forawi, S. (2019). *Teacher Perceptions of the New Mathematics and Science Curriculum : A Step Toward STEM Implementation in Saudi Arabia*. 8(3), 202–233. <https://doi.org/10.5539/jel.v8n3p202>
- Mafugu, T., Tsakeni, M., & Jita, L. C. (2022). Preservice Primary Teachers' Perceptions of STEM-Based Teaching in Natural Sciences and Technology Classrooms. *Canadian Journal of Science, Mathematics and Technology Education*, 22(4), 898–914. <https://doi.org/10.1007/s42330-022-00252-z>
- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. In *International Journal of STEM Education* (Vol. 6, Issue 1). Springer. <https://doi.org/10.1186/s40594-018-0151-2>
- Martínez-Borreguero, G., Naranjo-Correa, F. L., & Mateos-Núñez, M. (2022). Cognitive and Emotional Development of STEM Skills in Primary School Teacher Training through Practical Work. *Education Sciences*, 12(7). <https://doi.org/10.3390/educsci12070470>
- Mateos-Núñez, M., Martínez-Borreguero, G., & Naranjo-Correa, F. L. (2020). Learning science in primary education with STEM workshops: Analysis of teaching effectiveness from a cognitive and emotional perspective. *Sustainability (Switzerland)*, 12(8). <https://doi.org/10.3390/SU12083095>
- Meier, R. M., & Hendel, S. A. (2019). A Project-Based Learning Unit Plan: An Inquiry into Frogs. *Open Journal of Social Sciences*, 07(11), 70–78. <https://doi.org/10.4236/jss.2019.711006>
- Mercan, Z., Papadakis, S., Can Gözümlü, A. İ., & Kalogiannakis, M. (2022). Examination of STEM Parent Awareness in the Transition from Preschool to Primary School. *Sustainability (Switzerland)*, 14(21). <https://doi.org/10.3390/su142114030>
- Micari, M., & Pazos, P. (2020). Beyond grades : improving college students ' social - cognitive outcomes in STEM through a collaborative learning environment. *Learning Environments Research*, 0123456789. <https://doi.org/10.1007/s10984-020-09325-y>
- Ng, C. H., & Adnan, M. (2018). Integrating STEM education through Project-Based Inquiry Learning (PIL) in topic space among year one pupils. *IOP Conference Series: Materials Science and Engineering*, 296(1). <https://doi.org/10.1088/1757-899X/296/1/012020>
- Nguyen, N. T. P., & Tran, L. H. (2024). Uncovering the Challenges and Requirements of Elementary School Teachers in Implementing STEM Educational Activities in Vietnam. *International Journal of Learning, Teaching and Educational Research*, 23(6), 373–390. <https://doi.org/10.26803/ijlter.23.6.17>
- Ow-Yeong, Y. K., Yeter, I. H., & Ali, F. (2023). Learning data science in elementary school mathematics: a comparative curriculum analysis. *International Journal of STEM Education*, 10(1). <https://doi.org/10.1186/s40594-023-00397-9>
- Safiee, N., Jusoh, Z. M., Noor, A. M. H. M., Tek, O. E., & Salleh, S. M. (2018). An early start to STEM education among year 1 primary students through project-based inquiry learning in the context of a magnet. *IOP Conference Series: Materials Science and Engineering*, 296(1). <https://doi.org/10.1088/1757-899X/296/1/012023>

- Sari, L. S., Fitriani, P., Tresnawati, N., & Khodari, R. (2024). STEM Approach to 4C Skills in Elementary School Students: A Systematic Literature Review. *Scientiae Educatia: Jurnal Pendidikan Sains*, 13(1), 10–27. <https://doi.org/10.24235/sc.educatia.v13i1.18062>
- Singh-pillay, A., & Naidoo, J. (2020). Context Matters : Science , Technology and Mathematics Education Lecturers ' Reflections on Online Teaching and Covid-19 Pandemic. *Journal of Baltic Science Education*, 19(6A), 1125–1136.
- Siregar, Y. E. Y., Rachmadtullah, R., Pohan, N., Rasmitadila, & Zulela. (2019). The impacts of science, technology, engineering, and mathematics (STEM) on critical thinking in elementary school. *Journal of Physics: Conference Series*, 1175(1). <https://doi.org/10.1088/1742-6596/1175/1/012156>
- Slim, T., van Schaik, J. E., Dobber, M., Hotze, A. C. G., & Raijmakers, M. E. J. (2022). Struggling or Succeeding in Science and Technology Education: Elementary School Students' Individual Differences During Inquiry- and Design-Based Learning. *Frontiers in Education*, 7. <https://doi.org/10.3389/educ.2022.842537>
- Smyrnova-Trybulska, E., Morze, N., Kommers, P., Zuziak, W., & Gladun, M. (2016). *Educational Robots in Primary School Teachers' and Students' Opinion About STEM Education for Young Learners*. www.roboty.bielsko.pl,
- Temelli, S., Etkinliklerinin, R., & Adayları, Ö. (2022). *The Effect of STEM and STEM-Based Robotics Activities on Constructive Learning Environments Opinions of Teacher Candidates*. 12, 137–163. <https://doi.org/10.21733/ibad.948455>
- Thao, N. P., Huong, L. T. T., Dinh, N. V., Hang, N. T. T., Quyen, C. V., Cuong, L. M., & Thao, T. T. P. (2024). Current Situation of Primary School Teachers' Integrated STEM Teaching Competence: An Exploratory Study in The Northern Mountainous Provinces of Vietnam. *Jurnal Pendidikan IPA Indonesia*, 13(1), 64–75. <https://doi.org/10.15294/jpii.v13i1.49636>
- Toma, R. B., & Greca, I. M. (2018). The effect of integrative STEM instruction on elementary students' attitudes toward science. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(4), 1383–1395. <https://doi.org/10.29333/ejmste/83676>
- Tresnawati, N., Saleh, I., Kurniawan, D. T., Sudarmin, S., & Wardani, S. (2019). *Learning Science Through STEAM Approach (Science Technology, Engineering, Arts, and Mathematics) Integrated Ethnoscience in the Context of Batik Culture for Pre Service Teachers of Primary Education* (Vol. 429). <https://www.youtube.com/watch?v=WssJrCqDqN0&feature=s>
- Tresnawati, N., Saleh, I., Sudarmin, & Wardani, S. (2021). Science Batik Ciwaringin: The Implementation of Ethno-STEM PjBL Model in learning Biotechnology at PGSD Students. *Journal of Physics: Conference Series*, 1842(1). <https://doi.org/10.1088/1742-6596/1842/1/012063>
- Tuyet, T. L. T., Thi, K. N., Duc, H. T., Giao, X. T. T., Thi, N. V., Tuong, V. H. K., Nhu, U. D. T., & Mai, A. L. T. (2024). STEM education in primary schools of Southeast Asian countries: An analysis of scientific publications in the Scopus database from 2000 to 2022. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(4). <https://doi.org/10.29333/ejmste/14432>

- Tytler, R., Prain, V., & Hobbs, L. (2019). *Rethinking Disciplinary Links in Interdisciplinary STEM Learning : a Temporal Model*.
- Way, J., Preston, C., & Cartwright, K. (2022). STEM 1, 2, 3: Levelling Up in Primary Schools. *Education Sciences*, 12(11). <https://doi.org/10.3390/educsci12110827>
- Yahya, M. S., & Hashim, H. (2021). *Interdisciplinary Learning and Multiple Learning Approaches in Enhancing the Learning of ESL among STEM Learners*. 1057–1065. <https://doi.org/10.4236/ce.2021.125078>
- Yalçın, V. (2021). *The Effect of STEM Activities Prepared According to the Design Thinking Model on Preschool Children ' s Creativity and*. 41(May). <https://doi.org/10.1016/j.tsc.2021.100864>
- Županec, V., Radulović, B., & Lazarević, T. (2022). Instructional Efficiency of STEM Approach in Biology Teaching in Primary School in Serbia. *Sustainability (Switzerland)*, 14(24). <https://doi.org/10.3390/su142416416>