Primary School STEM Education Innovation through ICT Integration for Teacher Competency Development: A Systematic Literature Review

Inovasi Pendidikan STEM Sekolah Dasar melalui Integrasi TIK untuk Pengembangan Kompetensi Guru: Tinjauan Literatur Sistematis

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Abstract: *This study examines the integration of Information and Communication Technology (ICT) to enhance STEM learning in primary schools. Conducted via a systematic literature review (SLR) following PRISMA guidelines, articles from 2020 to 2024 were analyzed using Scopus. The findings underscore the profound impact of ICT integration on bolstering STEM education in primary settings. Effective implementation requires tailored teacher training programs and a comprehensive understanding of primary education dynamics. Despite challenges, addressing the nuanced needs and perceptions within primary education is imperative for advancing the quality of STEM education. Consequently, providing teachers with requisite support, including targeted training initiatives and a nuanced grasp of primary education requirements, is vital for fortifying the efficacy of STEM education in the future. To conclude, fostering a synergy between STEM and ICT yields significant enhancements in primary school learning outcomes.*

Keywords: *learning technology, STEM, ICT integration, elementary education*

Abstrak: *Studi ini mempelajari integrasi Teknologi Informasi dan Komunikasi (TIK) untuk memperkaya pembelajaran STEM di sekolah dasar. Studi dilakukan melalui tinjauan literatur sistematis (systematic literature review,* SLR*) yang mengikuti pedoman PRISMA. Artikel-artikel yang ditelaah berasal dari Scopus yang terbit dari tahun 2020 hingga 2024. Temuan-temuan menggarisbawahi dampak mendalam dari integrasi TIK dalam memperkuat pendidikan STEM di sekolah dasar. Implementasi STEM dan TIK yang efektif membutuhkan program pelatihan guru yang disesuaikan dan pemahaman yang komprehensif tentang dinamika pendidikan dasar. Meskipun ada tantangan, memenuhi kebutuhan dan persepsi yang berbeda dalam pendidikan dasar sangat penting untuk memajukan kualitas pendidikan STEM. Oleh karena itu, memberikan dukungan yang diperlukan kepada para guru, termasuk inisiatif pelatihan yang ditargetkan dan pemahaman yang baik tentang kebutuhan pendidikan dasar, sangat penting untuk memperkuat efektivitas pendidikan STEM di masa depan. Kesimpulan, membina sinergi antara STEM dan TIK akan menghasilkan peningkatan yang signifikan dalam hasil pembelajaran di sekolah dasar.*

Kata kunci: *teknologi pembelajaran, STEM, integrasi TIK, pendidikan dasar*

INTRODUCTION

Primary school education plays an integral role in shaping the foundational knowledge and skills of students (Pujasmara, Herawati, & Susanto, 2023). In recent years, there has been a significant increase in attention to STEM (Science, Technology, Engineering, and Mathematics) education at the elementary school level (Ndijuye & Tandika, 2020). STEM involves various methods for visualizing data, including graphs, diagrams, and 2D and 3D models, which not only expand our ability to manage information but also actively engage our visual-spatial thinking (Balakrisnan, Kamarudin, Ma'rof, & Hassan, 2023). The focus on STEM curriculum development in schools has emerged as a pressing need, prompting a deeper understanding of the importance of integrating these four disciplines (Pujasmara *et al*., 2023).

The application of STEM practical experiences aims to stimulate positive development in the cognitive, affective, and self-efficacy aspects for primary school teachers (Martínez-Borreguero, Naranjo-Correa, & Mateos-Núñez, 2022). The importance of STEM education at the elementary school level extends beyond mastering scientific and mathematical concepts (Setyowati, Firda, & Kasmita, 2021). STEM education stimulates critical and creative thinking, aiding students in developing logical, analytical, and problem-solving skills (Dúo-Terrón, 2023). Emphasizing STEM curriculum development fosters close linkages between subjects, reflecting the integrated and complex sustainability of the universe (Hourigan, O'Dwyer, Leavy, & Corry, 2024).

STEM (Science, Technology, Engineering, and Math) education has a significant positive impact on student development (Tsichouridis, Batsila, & Vavougios, 2020), particularly in fostering a holistic and interdisciplinary mindset (Wan, So, & Zhan, 2023). The STEM curriculum encourages students to integrate knowledge and skills from various disciplines (Sirait, Putri, Adishy, Hasby, & Hasibuan, 2023), enabling them to understand the interconnectedness of subjects and adapt to diverse learning styles (Syahrir. et al., 2023). Through this approach, students not only gain a deep understanding of science and math concepts but also develop critical thinking, problem-solving, and team collaboration skills (Pujasmara et al., 2023).

By designing practical projects and multidisciplinary challenges, the STEM curriculum motivates students to apply their knowledge in real-world contexts (Yllana-Prieto, González-Gómez, & Jeong, 2023), thereby creating a learning environment that stimulates creativity and innovation (Romero-Rodríguez, De la Cruz-Campos, Navas-Parejo, & Martínez-Domingo, 2023). Consequently, STEM education not only prepares students to become experts in specific fields but also cultivates a holistic mindset, equipping them to face complex challenges in an ever-evolving modern society (Sujarwanto, 2023).

Technological innovation is crucial in the context of STEM education, as it provides innovative tools and platforms that effectively support the learning process (Mateos-Núñez, Martínez-Borreguero, & Naranjo-Correa, 2020). Emerging learning approaches, such as the Internet of Things (IoT), 3D printing, E-learning, Robotics, and Artificial Intelligence (AI), facilitate a more immersive and interactive student experience (García-Sánchez, Candia-García, & Vargas-Martínez, 2024). Technology meets the need for dynamic and adaptive learning tools, allowing teachers to create learning experiences tailored to the individual needs of students (Arabit García, Prendes Espinosa, & Serrano Sánchez, 2021).

Innovative tools, such as Augmented Reality (AR), hold significant potential for application in education without compromising rigor and relevance (Mukhtarkyzy, Abildinova, Serik, Kariyeva, & Sayakov, 2023). Collaborative

platforms further enhance student interaction, enabling them to work together on STEM projects and develop social and problem-solving skills collaboratively (Parmaxi, Christou, Fernández Valdés, Puente Hevia, Perifanou, Economides, *et al*, 2024).

The integration of technology in STEM education at the primary school level reflects significant recent advancements, with the application of various technologies aimed at enhancing students' learning experiences (García Terceño, Greca, Redfors, & Fridberg, 2021). This includes the use of simulation software, interactive learning applications, and hardware such as tablets and computers (Hourigan et al., 2024). These technologies are designed to provide a more dynamic and practical approach to learning, allowing students to engage more actively in the learning process (Septiyanto, Oetomo, & Indriyanti, 2024).

Evaluations of the impact of technology on student learning indicate increased engagement, motivation, and comprehension of concepts (Vossen, Land-Zandstra, Russo, Schut, Van Vulpen, Watts, et al, 2023). Additionally, technology facilitates collaborative learning (Yegorina, Armstrong, Kravtsov, Merges, & Danhoff, 2021), enabling students to work together on STEM projects (García-Holgado, Gonzalez-González, & Peixoto, 2021). Through the integration of technology in STEM education at the elementary level (Hourigan et al., 2024), students can develop a solid foundation in science, technology, engineering, and mathematics while acquiring skills relevant to the digital age (Septiyanto et al., 2024).

STEM research in primary school education is crucial for building the foundation of children's knowledge and skills. Critical and creative thinking abilities, essential for addressing challenges in today's technological era, are developed through this foundation. This research can aid in designing a comprehensive curriculum that holistically integrates mathematics, engineering, science, and technology. Furthermore, the research can guide how to best foster students' interest and motivation toward science and technology, forming the basis for their future career choices. Nonetheless, integrating technological innovations into STEM education curricula at the primary school level presents several significant challenges and opportunities (Wan et al., 2023). A major challenge is teachers' understanding and readiness to adopt technology in their teaching practices (Lane, Kaya-Capocci, Kelly, O'Connell, & Goos, 2022), especially for those who may not be fully familiar with the latest devices and applications. Additionally, infrastructure and resource constraints in some educational settings can limit students' access to necessary technology (Syafe'i, Widarti, Dasna, Habiddin, Parlan, & Wonorahardjo, 2024).

More thorough research on STEM education in primary schools is imperative because it highlights a crucial component of laying the groundwork for children's education. Such studies can precisely describe how the inclusion of STEM concepts in the elementary school curriculum can significantly influence the cognitive and skill development of students. By understanding the best STEM teaching practices, research contributes significantly to the development of a strong foundation of transferable knowledge and abilities. Moreover, studying how to engage students in STEM courses and helping them realize their potential, as well as encouraging the identification of unique abilities and interests, can be facilitated through this research.

Despite these challenges, significant opportunities exist. The application of technology has the potential to enhance student participation by providing a more engaging and relevant learning experience (Fernández-Martín, Arco-Tirado, Carrillo-Rosúa, Hervás-Torres,

Ruiz-Hidalgo, & Romero-López, 2020). Through an in-depth examination of how technological innovations are not only complementary but also key determinants in shaping students' learning experiences at the primary school level (Mazas Gil, Cascarosa Salillas, & Cortés Gracia, 2020), this research aims to provide a robust knowledge base and deep insights for education practitioners, policymakers, and researchers. This will help them better understand how technological innovation can play an integral role in achieving STEM education goals at the primary school level. Based on this premise, the researcher will conduct a systematic literature review (SLR) to provide an in-depth analysis of:

a) The extent of information and communication technology (ICT) integration in enhancing STEM learning in primary schools.
b) Teachers' and students' beliefs about STEM and their perceptions of training and resources in primary schools.
c) How teachers' and students' attitudes towards STEM and perceptions of basic education and resources affect teachers' effectiveness in developing cognitive, affective skills, and pedagogical knowledge in STEM.

The findings of this research are expected to offer a deeper understanding of ICT integration in improving STEM learning in primary schools, facilitating the effective application of these insights to achieve Indonesia's educational goals in fostering a proud golden generation.

METHODS

This study employed the systematic literature review (SLR) method, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. PRISMA systematically and critically collects, (Lame, 2019), evaluates, and presents the results of literature searches (Nursalam, 2020). This structured approach not only provides a clear framework for literature searches but also enhances the synthesis and accessibility of information, supporting efficiency and precision in knowledge acquisition (Triandini, Jayanatha, Indrawan, Werla Putra, & Iswara, 2019). The PRISMA method comprises four stages: identification, screening, eligibility, and inclusion. The stages are as follows:

1) Identification Stage: Journal articles were searched through Scopus (https://www.scopus.com/) using the keywords "Technology," "STEM," and "Primary Education." The initial search on January 18, 2024, yielded 104 articles.
2) Screening Stage: During this stage, all articles were assessed based on inclusion criteria such as publication within the last five years (2020-2024), document type (articles), and open access status. Based on these criteria, 71 articles were selected.
3) Eligibility Stage: Articles were further evaluated for content relevance to the research question and summarized in a data mapping table for effective analysis. In this stage, 7 articles were excluded based on specific exclusion criteria.
4) Inclusion Stage: Finally, the researcher conducted a detailed review of the 7 articles that met the criteria related to "Technology," "STEM," and "Primary Education."

Illustration of the article selection process is seen on Figure 1.

RESULTS AND DISCUSSION

Results

A total of 7 research articles published between 2020 and 2024 met the inclusion criteria, focusing on "Technology," "STEM," and "Primary Education" to achieve educational goals at the primary school level. The data is presented in Table 1, which lists Scopus Indexed Journal Publications.

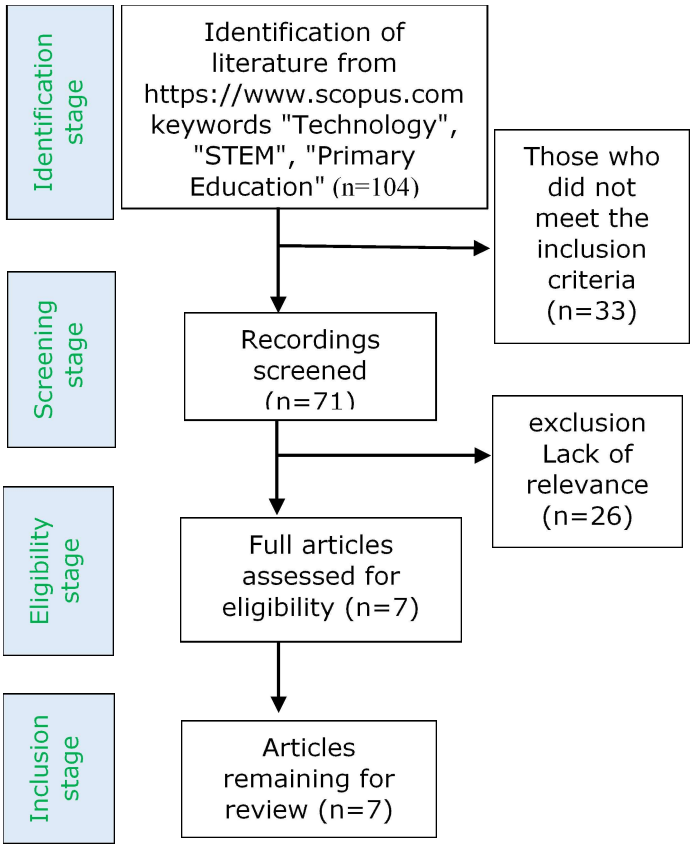

Figure 1 Diagram Search Terms and Publication Selection Process (PRISMA Flowchart)

Table 1 Scopus Indexed Journal Publications

Article Code	Title, Research Methods, and DOI	Author Name and Year of Publication	Results
A1	Title: New Methodology for Developing STEAM Projects According to the National Curriculum. Research Methods: Descriptive analysis Method DOI: 10.3390/ educsci13020169	(Montés, Zapatera, Ruiz, Zuccato, Rainero, Zanetti, *et al* 2023)	The developed methodology assists teachers in designing STEM projects. Curriculum analysis showed that more than 90% of curriculum groups from Mathematics, Fine Arts, and Natural Science subjects belong to STEAM groups, while only 60% from Social Science subjects do. Eleven thematic areas in Science, four in Technology, nine in Engineering, five in Arts, and ten in Mathematics were identified. The "forward" and "backward" methods were used to analyze the curriculum and develop thematic areas. Findings indicate that integrating arts into STEM learning is necessary for creating integrated and creative learning.

A2	Title: Cognitive and Emotional Development of STEM Skills in Primary School Teacher Training through Practical Work Research Methods: Quasi Experimental DOI: 10.3390/ educsci12070470	(Martínez-Borreguero et al., 2022)	The implementation of STEM practical activities significantly increased participants' scientific-technological knowledge and teaching efficacy. Positive emotional changes, including increased confidence and interest and decreased boredom and anxiety, were also noted. The results demonstrate that STEM education effectively enhances future teachers' cognitive abilities and teaching efficacy, and the integration of science and technology disciplines through practical workshops can be implemented in primary school classrooms.
A3	Title:Supporting Pre-service Elementary School Teachers' PCK and CK Development through STEM Programmes Research Methods: Mixed Methodology DOI: 10.3390/ educsci12040258	(Correia & Baptista, 2022)	The STEM program positively impacts pre-service teachers' knowledge and skills, with some misconceptions noted. The integration of STEM disciplines in teacher education and continuous professional development is crucial. Emphasizing STEM frameworks and complex physics topics in teacher education is essential. Challenges and benefits of technological approaches, inquiry-based learning, and student-centered pedagogy are recognized. Despite challenges in integrating STEM disciplines, pre-service teachers acknowledge the benefits for student learning.
A4	Title: STEM education in primary education from a gender perspective. Research Methods: Exploratory and non-experimental DOI: 10.12795/ REVISTAFUENTES.2021. V23.I1.12266	(Arabit García et al., 2021)	This article investigates primary school teachers' and students' beliefs about STEM education, alongside teachers' perceptions of training needs and resource availability. Data from 141 students and 67 teachers across seven primary schools in the Region of Murcia, Spain, were collected using a questionnaire. Findings reveal that while most teachers view teaching STEM as important, opinions vary on the adequacy of time allocated to these subjects. Gender disparities exist in teachers' views on STEM teaching methods and resource availability. The outcomes inform the development of teacher training programs and enhance STEM teaching methodologies in primary schools.

A5	Title: Interest in STEM among children with low socioeconomic status: further support for the STEM-CIS instrument through an adapted Dutch STEM-LIT measurement instrument Research Methods: Research and Development DOI: 10.1080/2331186X.2020.1745541	(Grimmon et al., 2020)	This article discusses the development and validation of the STEM Career Interest Survey (STEM-CIS) instrument, adapted for Dutch pupils and renamed the Science Technology Engineering Mathematics Leiden Interest Test (STEM-LIT). The study aimed to measure the interest of children aged 10-12 in STEM, particularly those from low socioeconomic status families. The instrument showed high reliability and validity when administered to children aged 9-14. Further validation for different target groups, languages, regions, and socioeconomic groups is recommended. The article is published under a Creative Commons Attribution (CC-BY) 4.0 license, allowing for sharing and adaptation with appropriate credit.
A6	Title: Methodology & Technology for teaching STEM in Primary Education: A needs analysis Research Methods: Mixed Methodology DOI: 10.12795/pixelbit.2020.i57.04	(Arabit García & Prendes Espinosa, 2020)	The study discussed in this article shows that teachers in the Región de Murcia, Spain, need more resources and training for better STEM teaching in primary schools. Students desire increased experimentation and the use of new technologies in STEM learning. Emphasizing the importance of integrating Information and Communication Technologies (ICTs) in STEM teaching, the study underscores the need for teachers to develop digital competencies. Despite recognizing the importance of STEM education, teachers felt underserved in terms of training and expressed the need for more resources and specialized labs. The study also highlighted students' motivation and effort in learning STEM subjects, although teachers gave a low assessment of the quality of STEM teaching in Spain. It underlines the importance of improving teacher training in the use of technology, innovative methodologies, and the provision of specialized resources. The research was funded by the European Commission, which emphasized the importance of improvements in STEM education.
A7	Title:Exploratory analysis of the implementation and use of smart platforms for learning in primary education	(Lara Nieto-Márquez et al., 2020)	This research examined the utilization of the Smile and Learn platform in Spanish public schools, finding high engagement in Science and Logic activities, especially among 1st Cycle students in Pilot Group

	1. Variations in usage were noted across pilot groups and school classifications, highlighting the need for enhanced digital materials, interdisciplinary integration, and teacher training. The study suggested potential research avenues focusing on educational cycles or classes with special needs. It also offered insights into the platform's efficacy in promoting active learning and underscored the role of personal preferences and teacher motivation in its utilization.

Source: Author, 2024

Discussion

Integration of Information and Communication Technology (ICT) in Enhancing STEM Learning in Primary Schools

Research findings by Arabit García & Prendes Espinosa (2020) A6 underscored students' inclination towards experiencing and utilizing new technologies in their STEM learning endeavors. These results reveal a pressing exigency to incorporate information and communication technology (ICT) within STEM education frameworks in primary schools. However, the significance of educators' digital competencies in orchestrating and executing technology-driven curricula was also underscored. Although a majority of educators acknowledge the importance of imparting STEM education, they concurrently acknowledge the deficiency in adequate training and the necessity for augmenting STEM education resources and laboratories.

Research conducted by Montés, Zapatera, Ruiz, Zuccato, Rainero, Zanetti, *et al*, (2023) A1 corroborated prior findings by accentuating the efficacy of the developed methodology in aiding educators to conceptualize STEM projects. Curriculum scrutiny evinced a substantial representation of curriculum clusters in the STEAM domain, whereas Social Studies exhibited a diminished proportion. Moreover, the significance of integrating arts within the STEAM paradigm to foster comprehensive and imaginative learning was acknowledged, thereby instigating a call for tailored pedagogical training to integrate STEM seamlessly into educational frameworks.

The integration of STEM with the utilization of ICT brings about positive changes in education by stimulating students' interest and motivation through the use of modern technology (May, Wendt, & Barthlow, 2022). Engaging and relevant learning experiences through interactive software and simulations enrich students' understanding of science, technology, engineering, and math concepts. Additionally, the utilization of ICT enables student collaboration in completing STEM projects, shaping collaborative skills that are essential in the modern world of work.

However, this integration also faces several challenges such as gaps in access to technology, the need for teacher training, and changes in the curriculum. Continuous evaluation of student learning outcomes, engagement levels, and the impact of STEM integration with ICT are key assessments to measure the success of this approach in preparing students for an increasingly digitalized future (Bardoe, Hayford, Bio, & Gyabeng, 2023). The development of information and communication technology (ICT) has brought about substantial changes in education, considering it as a pivotal element in delivering

materials, particularly at the primary education level and in STEM subjects. The holistic approach of STEM, which incorporates science, technology, engineering, and math, fosters critical thinking skills, creativity, and problem-solving abilities. In an era where technology permeates daily life, education needs to respond and utilize the potential of ICT integration, particularly in STEM subjects at the basic education level. ICT integration is expected to have a positive impact on student motivation and learning outcomes.

With an in-depth understanding of the impact of ICT integration, this research is expected to make a significant contribution to developing effective teaching strategies that meet the challenges of the times (Bardoe et al., 2023). Overall, the integration of information and communication technology (ICT) plays a key role in improving STEM learning in primary schools. The methodology developed supports teachers in designing STEM projects, and the curriculum analysis underscores the need for ICT integration to enhance the effectiveness of STEM learning at the primary education level. The importance of specialized training for teachers to integrate STEM into the school system is also a critical aspect that can be applied in the context of ICT integration.

Teachers' and Students' Beliefs Toward STEM and Their Perceptions of Training and Resources in Primary Schools

Research conducted by Martínez-Borreguero et al. (2022) A2 revealed that the implementation of STEM practicum activities significantly enhanced participants' science-technology knowledge and teaching effectiveness. These activities also engendered positive emotional changes, such as increased confidence and interest, alongside decreased boredom and anxiety. These findings underscore the efficacy of STEM education in augmenting the cognitive abilities and teaching efficacy of prospective educators. However, it is imperative to investigate the degree to which beliefs and perceptions regarding STEM have been integrated into the primary school milieu. Aligning with research insights, the integration of learning across science and technology disciplines via practical workshops in primary schools is advocated, suggesting its feasibility within classroom settings. Hence, a comprehensive assessment of how beliefs and perceptions toward STEM manifest in school policies, teacher training, and the availability of resources in primary education is crucial for bolstering the effectiveness of STEM education.

Corroborating these findings, Correia & Baptista (2022) A3 found that STEM programs positively impacted pre-service teachers' knowledge and skills. Notably, the program played a pivotal role in enhancing pre-service teachers' comprehension of STEM integration principles. This underscores the importance of incorporating various STEM disciplines into teacher education curricula and fostering ongoing professional development in STEM education. Moreover, interrogating teachers' and students' beliefs and perceptions can offer valuable insights. Teacher education programs should prioritize the integration of STEM frameworks and provide avenues for prospective educators to fortify their knowledge, particularly in intricate physics topics. Acknowledging the challenges and merits of technological approaches, inquiry-based learning, collaborative learning, meaningful contexts, student-centered pedagogy, design-based learning, and 21st-century skills in STEM education, as highlighted by pre-service teachers, provides a foundation for further exploration of their beliefs and perceptions. Despite potential misconceptions, pre-service teachers' capacity to devise lesson plans integrating STEM content and instructional practices underscores the promising potential of STEM programs (Bardoe et al., 2023).

Martínez-Borreguero et al. (2022) A2 and Correia & Baptista (2022) A3 collectively present an optimistic outlook on the implementation of STEM practicum activities and STEM programs in education. The former study demonstrated that STEM practicum significantly enhanced participants' science-technology knowledge and teaching efficacy, while positively affecting emotional aspects such as increased confidence and interest, alongside reduced boredom and anxiety. These findings highlight the efficacy of STEM education in enhancing prospective teachers' cognitive abilities and teaching efficacy. The latter study affirmed the positive impact of STEM programs on pre-service teachers' knowledge and skills, playing a crucial role in bolstering their understanding of STEM integration principles.

Both studies underscore the significance of integrating practical approaches and STEM programs in cultivating STEM education at the primary level. The implementation of STEM practicums and the emphasis on integrating STEM frameworks in teacher education programs have positively influenced participants' beliefs and understanding. Recognizing the challenges and benefits of technological approaches, inquiry-based learning, and 21st-century skills is paramount. Hence, further assessment of how beliefs and perceptions of STEM are reflected in school policies, teacher training, and resource availability in primary education settings is indispensable for fostering more effective STEM education.

Teachers' and Students' Attitudes Towards STEM and Perceptions of Basic Education and Resources

The study by Lara Nieto-Márquez, Baldominos, Cardeña Martínez, & Pérez Nieto (2020) A7 offers a detailed examination of the utilization of the Smile and Learn platform in Spanish public schools. The analysis underscores the significant engagement in Science and Logic activities, particularly among Cycle 1 students in Pilot Group 1. Notably, the study delineates substantial variances in the utilization of the educational universe and activities across different pilot groups and school classifications, while also spotlighting diverse approaches to platform implementation.

Moreover, findings from research by Grimmon et al., (2020) A5 suggest that attitudes of both teachers and students toward STEM, alongside perceptions of basic education and resource availability, wield considerable influence on the efficacy of teachers in developing cognitive, affective skills, and pedagogical knowledge in STEM domains. Within this context, an article discusses the development and validation of the STEM-Career Interest Survey (STEM-CIS) instrument adapted for Dutch students into the Science Technology Engineering Mathematics Leiden Interest Test (STEM-LIT). The study, focusing on students' interests, exhibited high reliability and validity of the instrument, with particular emphasis on children aged 10-12 from families with low socioeconomic status.

Furthermore, Grimmon, Cramer, Yazilitas, Smeets, & De Bruyckere (2020) A5 exploring primary school teachers' and students' beliefs regarding STEM education, as well as teachers' perceptions of training and resource availability in school settings, illustrated that while the majority of teachers recognized the significance of integrating STEM into the primary school curriculum, divergent viewpoints emerged concerning the allocation of time to STEM subjects. Gender disparities also surfaced in teachers' perceptions of STEM instruction methods and resource availability in schools, highlighting the multifaceted challenges teachers encounter in STEM integration, especially from a gender perspective. This study not only delves into teachers' perspectives but also assesses the needs of students and teachers in STEM education, underscoring

disparities between teachers and students, including differential comprehension of STEM among female and male educators. The findings lay the groundwork for crafting more targeted teacher training programs, refining STEM teaching methodologies, and comprehensively grasping needs and perceptions within the realm of basic education.

STEM programs serve as pivotal avenues for enriching Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) among prospective primary school educators. The examination of the Smile and Learn platform's utilization highlighted significant variations in educational usage and activities between the pilot group and other schools, accentuating the necessity for digital material development and teacher training. Insights into teachers' and students' attitudes toward STEM, coupled with the intricate challenges of integration, underscore the significance of tailored training strategies and a comprehensive understanding of needs and perceptions within primary education contexts. In summation, bolstering future innovations and enhancements in education policy will be instrumental in augmenting the efficacy of STEM instruction at the elementary education level.

Integrating STEM (Science, Technology, Engineering, and Mathematics) into elementary schools represents a critical stride in introducing fundamental concepts across the curriculum. This integration is facilitated through project-based learning methodologies spanning various subjects. Concurrently, leveraging ICT (Information and Communication Technology) in instruction provides substantial added value. Teachers can deliver materials in a more engaging and comprehensive manner to students through diverse digital media and interactive learning tools. The fusion of STEM and ICT not only invigorates teaching in elementary schools but also equips students with future-relevant skills.

The positive ramifications of this integration are profound. For teachers, ICT utilization enhances teaching efficacy by rendering materials more interactive and captivating, while also facilitating student progress monitoring. Conversely, for students, learning becomes more enjoyable and adaptable, with access to diverse digital resources enriching their educational journey. Technologies such as Augmented Reality (AR) and Virtual Reality (VR) further offer innovative and immersive learning encounters. Overall, the integration of STEM and ICT not only equips students with pertinent skills and knowledge for future success but also establishes a contemporary and adaptable educational framework to meet the imperatives of the digital age.

CONCLUSION AND RECOMMENDATION

Conclusion

The integration of STEM at the elementary school level represents a pivotal stride in introducing foundational concepts across the curriculum. This integration is facilitated through comprehensive project-based learning methodologies, enabling the application of materials across diverse subjects. Additionally, leveraging ICT in the learning process provides substantial added value. Teachers can deliver materials in a more engaging and comprehensive manner with the aid of digital media and interactive learning tools. The amalgamation of STEM and ICT not only invigorates the learning environment in elementary schools but also equips students with skills pertinent to the future.

The positive impact of this integration is profound. For teachers, the utilization of ICT enhances teaching efficacy, augmenting teaching methods with more captivating and easily comprehensible materials. Meanwhile, for students, learning becomes more enjoyable and adaptable, with access to various digital resources enriching their educational

experiences. The incorporation of technologies such as Augmented Reality (AR) and Virtual Reality (VR) further offers innovative and immersive learning encounters. Overall, the integration of STEM and ICT not only equips students with skills and knowledge relevant for the future but also establishes a modern and responsive educational foundation amid the evolving digital era.

In conclusion, the implementation of STEM at the elementary school level significantly enhances teachers' confidence and teaching effectiveness, as well as students' knowledge and skills. STEM programs enhance comprehension of science and technology concepts and teaching effectiveness, while also enhancing students' emotional well-being by fostering confidence and interest and mitigating boredom and anxiety. Moreover, these programs play a pivotal role in enhancing teachers' understanding of STEM integration. Hence, STEM training and education for elementary school teachers and prospective teachers are imperative to ensure they possess the requisite skills to facilitate students in developing 21st-century learning abilities.

Recommendation

Drawing from the conclusions outlined, several recommendations can be posited in the academic and policy domains to fortify STEM integration at the elementary school level. Firstly, there should be a concerted emphasis on STEM training and education for elementary school teachers and prospective teachers to ensure they possess adequate knowledge and skills to implement STEM methodologies in teaching. Additionally, curriculum development should prioritize the comprehensive integration of STEM concepts and underscore the effective use of Information and Communication Technology (ICT) as a learning tool. Sustainable professional development initiatives are also essential to ensure that teachers continually refine their skills in embracing innovative STEM learning approaches.

On the policy front, governmental support in terms of funding and resources is imperative for the effective implementation of STEM programs in elementary schools. Furthermore, the development of robust ICT infrastructure in schools is crucial to ensure equitable access to the technology requisite for supporting STEM learning. By adhering to these recommendations, we can bolster elementary education in preparing students with pertinent skills and knowledge for the future, while erecting a modern and responsive educational framework tailored to the evolving digital landscape.

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