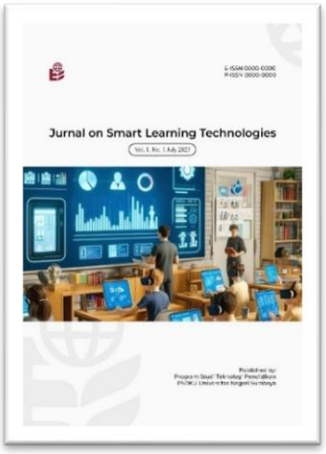

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Opportunities for STEM-based Learning Models in Elementary Schools

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Abstract

Enhancing STEM literacy in elementary education is becoming increasingly imperative to address global challenges and technology advancements that require critical, creative, and collaborative thinking skills from a young age. The theme and project-based learning (PjBL) approach employed in elementary classrooms demonstrates promise for the integration of STEM elements. Nevertheless, educators' comprehension of this methodology is constrained, and institutional support is suboptimal. This study seeks to examine the perspectives of educators and administrators concerning the opportunities for applying STEM-based learning models in primary schools, while also identifying existing educational practices that may facilitate STEM integration. The research employed an exploratory qualitative methodology, utilizing in-depth interviews and participant observation across various public and private primary schools. The findings indicate that educators possess favorable views of the STEM methodology and have adopted thematic learning approaches that implicitly incorporate STEM components, albeit in an unstructured manner. The primary supporting variables consist of teacher inventiveness and student excitement, whereas the principal impediments are inadequate training, facilities, and curriculum guidelines. The findings underscore the necessity of creating a contextual, adaptable STEM paradigm tailored to the peculiarities of elementary school kids, supported by teacher training and collaboration among educational partners.

Keywords: STEM learning, elementary school, teacher perception, thematic learning, project-based learning, contextual education, learning innovation

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INTRODUCTION

Enhancing STEM (Science, Technology, Engineering, and Mathematics) literacy in elementary education is becoming increasingly imperative due to global needs for the younger generation to possess critical thinking, collaboration, and problem-solving abilities. STEM literacy is deemed essential for equipping students to confront future difficulties and establishing a proficient workforce in the digital age (Cavalcanti & Mohr-Schroeder, 2019; Nugroho et al., 2021). Numerous studies underscore the

necessity of initiating STEM literacy in elementary education, as early engagement with STEM can cultivate interests, scientific perspectives, and 21st-century competencies from a young age (Carter, 2020; Subramanian, 2020). Moreover, STEM education has demonstrated the capacity to enhance critical thinking, cooperation, and problem-solving abilities (Carter, 2020), which are essential components of the contemporary education system. Regrettably, the integration of STEM in primary school classrooms remains insufficiently prevalent, and research on methodologies for its implementation at this educational tier is still few.

Conversely, theme and project-based learning (PjBL), now incorporated into the elementary school curriculum in Indonesia, presents significant opportunity for the seamless and contextual integration of STEM methodologies. Studies indicate that PjBL-STEM enhances critical thinking abilities (Cavalcanti & Mohr-Schroeder, 2019; Kartimi et al., 2021), creativity (Lutfi et al., 2018), scientific literacy, and proficiency in scientific processes and project execution (Ali et al., 2024). This methodology facilitates active student participation and enables organized interdisciplinary exploration. The effectiveness of STEM integration in Project-based Learning (PjBL) is significantly contingent upon teacher preparedness, advanced pedagogical approaches, and sufficient curriculum and financial resources (Carter, 2020). The primary difficulty in elementary education is instructors' insufficient comprehension of interdisciplinary methods and the absence of structured implementation instructions. Consequently, it is essential to investigate the perspectives of educators and administrators and analyze real classroom learning practices to inform the development of a STEM learning model that is pertinent, applicable, and suitable for the characteristics of elementary school pupils.

Within the framework of Indonesia's elementary school curriculum, the theme and project-based learning approach (PjBL) possesses significant potential as a natural conduit for the integration of the STEM methodology. PjBL facilitates the amalgamation of multiple disciplines under a singular project that is relevant to students' experiences. This technique, when combined with STEM principles, has demonstrated enhancements in critical thinking skills (Jones et al., 2018), creativity, and overall educational achievements (Izzah & Mulyana, 2021). The greatest efficacy of PjBL-STEM was observed in junior high school mathematics education, indicating the applicability of this method at the elementary level as well (Izzah & Mulyana, 2021). The use of STEM in Project-Based Learning enhances scientific literacy, scientific process abilities, and the capacity to effectively execute projects. PjBL-STEM is regarded as a potential multidisciplinary method to enhance the quality of STEM teaching across multiple levels, including elementary schools.

Nonetheless, despite the high educational potential of PjBL-STEM, its implementation at the elementary school level encounters numerous hurdles, particularly concerning the poor comprehension and preparedness of educators. Numerous educators still lack a thorough comprehension of how to include STEM elements into a singular thematic project, particularly with the design of learning methodologies, the selection of activities, and interdisciplinary evaluations. The efficacy of this method

is significantly reliant on a developed plan and thorough evaluation (Cavalcanti & Mohr-Schroeder, 2019), which, in practice, have not been entirely grasped by elementary school educators. Furthermore, numerous educators have not had pertinent training or access to necessary STEM curriculum guidelines. Consequently, investigating the opinions of educators and administrators, as well as delineating actual classroom learning practices, are essential elements in formulating a pragmatic and contextual STEM learning model. This study aims to reconcile the theoretical promise of the PjBL-STEM approach with its practical use in primary schools.

While STEM education has been extensively examined at the secondary and university levels, research focusing on its application in elementary education, particularly within the Indonesian setting, remains scarce (Jackson et al., 2021). Most prior studies predominantly concentrate on certain areas in isolation, such as the mastery of scientific or mathematical information, neglecting comprehensive interdisciplinary integration or thematic approaches in early education. This study provides originality by directly investigating the perspectives of educators and administrators regarding themed learning techniques in elementary schools that inherently incorporate STEM principles. The findings of this study enhance the literature on contextual and experience-based STEM education and offer practical insights for educators and policymakers in formulating adaptive STEM integration techniques suitable for elementary school environments. This methodology aligns with the necessity for educational frameworks that promote 21st-century competencies and interdisciplinary learning from an early age (Carter, 2020; Cavalcanti & Mohr-Schroeder, 2019), and bolsters efforts to enhance teacher proficiency in delivering creative and pertinent education.

This study aims to explore in depth the perceptions and views of teachers and principals regarding the opportunities for implementing STEM-based learning models in elementary schools. In addition, this study also aims to identify actual learning practices that have the potential to support the integration of the STEM approach, especially in the context of thematic and project-based learning that has become a characteristic of the curriculum at the elementary education level. Through this approach, it is hoped that a more complete understanding will be obtained regarding the readiness and challenges of implementing STEM in elementary schools, as well as a strong basis for developing relevant and contextual learning models.

METHODS

This study employs a descriptive qualitative methodology (Sofaer, 2002) to thoroughly investigate the use of Augmented Reality (AR) in geography education and its impact on the enhancement of students' spatial skills at the Junior High School (SMP) level. This methodology was selected as it enables researchers to comprehend the phenomenon in a contextual and comprehensive manner by analyzing the experiences, perceptions, and interactions of individuals inside a learning environment utilizing AR technology (Gill, 2020). This study aims not to generalize the results but to achieve a comprehensive and nuanced understanding of the application of augmented reality in geography education within specific circumstances. This study was performed in two private junior high

schools in Surakarta City that have incorporated Augmented Reality-based media into the geography curriculum. The selection of places was conducted intentionally, considering the preparedness of schools to use instructional technology and the availability of teachers who actively employ AR media. The research participants comprised two primary groups: (1) five geography teachers who actively utilize augmented reality (AR) media in their instructional practices, and (2) eighth-grade students engaged in AR-based geography education at each institution. Subject selection was predicated on active engagement in the learning process central to the study, ensuring that the data collected accurately represented genuine experiences of utilizing the technology within a real classroom environment (Gill, 2020). The study employed two primary strategies for data collecting. Initially, conduct direct observation of geography learning activities utilizing Augmented Reality (AR) media in the classroom to discern interaction patterns, instructional tactics, and student responses throughout the process. Secondly, comprehensive interviews with teachers and students will be conducted to further investigate perspectives, learning experiences, and perceived effects associated with the utilization of augmented reality in comprehending spatial ideas. These two strategies synergistically enhance the acquisition of a comprehensive and profound understanding of the issue under investigation.

The gathered data were examined utilizing the interactive model of Miles and Huberman, comprising three primary stages (Lisa et al., 1967). The initial phase is data reduction, encompassing the sorting, selection, and concentration of data pertinent to the research objectives. The second stage, data presentation, involves structuring information through thematic narratives and matrices to enhance interpretation. The third stage involves developing conclusions and verification, which entails discovering patterns, linkages within categories, and assuring the consistency of findings through repeated confirmation processes. This methodology enables researchers to construct robust and credible interpretations of the gathered qualitative data.

To guarantee the authenticity and trustworthiness of the data in this investigation, various qualitative verification methods were employed. Initially, source triangulation was conducted (Gill, 2020), involving the comparison and validation of findings from diverse sources, including educators, learners, and pertinent supporting materials. This method is employed to enhance viewpoints and mitigate bias from a single party. Secondly, member checking was conducted (Djafar et al., 2021), which involved reconfirming the preliminary analytical results with research participants to ascertain that the researcher's interpretation aligned with the informant's experiences and intents. Third, an audit trail was established through comprehensive and methodical documenting of the whole study process, encompassing data collection and analysis, so enabling retracing by other parties if required. The amalgamation of these three methodologies enhances data integrity and augments the validity of the research findings together.

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RESULTS

Teachers' and Principals' Perceptions of STEM-Based Learning

In-depth interviews revealed that the majority of teachers and principals possessed a foundational comprehension of STEM-based learning as an integrative method encompassing science, technology, engineering, and mathematics within a singular educational activity. While the majority lacked a comprehensive understanding of the model's structure and its integrative concepts, educators shown receptiveness to this methodology. A teacher stated, "In my view, STEM education cultivates children's ability to think from multiple perspectives, rather than focusing on a singular subject." For instance, the study of science may encompass computation and creation.

Educators and administrators concurred that the STEM methodology is highly pertinent and essential for implementation in elementary education. This approach fosters critical thinking, active engagement, and problem-solving skills in pupils through exploratory activities. A principal stated, "A learning model such as STEM is beneficial for elementary school students, particularly those who enjoy hands-on activities." It is not solely about memorizing; they can also engage in direct application. A different educator remarked that project-based learning, along with STEM components, might enhance students' comprehension of the interconnections among disciplines in a tangible and contextual manner. Concerning implementation readiness, the majority of teachers acknowledged their need for training and direction in developing STEM education that aligns with the characteristics of elementary school pupils and the relevant curriculum. A teacher stated, "We require training to implement this." Understanding the subject alone is insufficient; without the ability to integrate it into a suitable lesson plan and exercises, challenges will persist. Nonetheless, there was optimism and anticipation that this methodology might be executed incrementally. The principal's endorsement of teachers' endeavors to implement this strategy was seen as a significant component, as articulated by a principal, "If there is a training program or external mentoring, we are prepared to assist teachers in adopting this STEM model." The informants' perceptions indicate that STEM-based learning is regarded as a promising approach for implementation in elementary schools, provided it is supported by enhanced teacher capability and sufficient resources.

Learning Practices That Potentially Support STEM Integration

Observations undertaken during grade III learning activities reveal significant potential for the integration of the STEM method in thematic and project-based learning practices within elementary schools. While not explicitly intended as STEM-focused education, some observed activities have interdisciplinary elements typical of this methodology, including science, technology, engineering, and mathematics. One observed activity involves constructing a height measuring instrument using cardboard and a ruler, wherein kids engage in designing and measuring the height of their peers. This assignment demonstrates the interplay between engineering principles (tool design) and mathematics

(measurement, result comparison, and unit interpretation). In a separate educational exercise, students monitor the development of potted plants over several days. They document daily variations in plant height and subsequently create a basic growth graph. This exercise encompasses elements of science (observation, data documentation) and mathematics (display of quantitative data and graphical representations). Technology integration is becoming evident in the creation of digital posters focused on energy conservation, as students utilize basic design software like Canva to communicate environmental campaign messaging. This project demonstrates the amalgamation of technological components with scientific content, as students are required to comprehend the notion of energy utilization while presenting the information visually and creatively. In a subsequent lecture, students were instructed to compute the volume of plastic garbage generated over the course of a week, followed by a discussion on recycling methods. This project integrated mathematics, science, and engineering, prompting students to engage in critical thinking around environmental challenges. The project of constructing a tiny bridge from popsicle sticks exemplified the STEM method most well. Students were instructed to collaborate in groups, devise the bridge's design, compute the requisite number of sticks, and evaluate its strength post-construction. This project exemplified a fundamental engineering methodology, integrating structural principles, mathematical computations, and teamwork, while fostering creativity and problem-solving abilities. The results of this observation are encapsulated in the subsequent table.

Table 1. Learning Activities Containing STEM Integration Potential

No.	Learning Activities	STEM Element Indications	Brief Description
1	Making a height measuring tool from cardboard	Engineering, Mathematics	Designing a simple tool and measuring students' height using units of length.
2	Plant growth observation	Science, Mathematics	Recording and converting growth data into graphs.
3	Digital poster on the theme of "saving energy" using Canva	Technology, Science	Using an app for a science-based energy campaign.
4	Calculating waste volume and discussing recycling	Mathematics, Science, Engineering	Linking waste data to creative recycling solutions.
5	Designing a mini bridge from ice cream sticks	Engineering, Mathematics	Collaboratively calculating, building, and testing the strength of a mini structure.

Overall, these data suggest that learning methods in elementary schools inherently exhibit traits of the STEM approach, despite lacking official or systematic implementation. Educators typically formulate contextual activities that promote exploration, observation, and production, which are essential components of a STEM-oriented learning methodology. This indicates that enhancing teacher competence and implementing more targeted learning strategies will significantly facilitate the comprehensive adoption of the STEM model in elementary education.

Supporting and Inhibiting Factors for STEM Implementation in Elementary Schools

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The interview findings reveal that the implementation of STEM-based learning in elementary schools is affected by a range of interconnected facilitating and obstructing factors. Regarding internal elements, educators exhibit significant ingenuity in crafting learning experiences through the use of basic materials. A teacher remarked, "We are accustomed to creating educational tools from recycled materials; therefore, if we are guided towards STEM, I believe we can adapt, we merely need to refine the concept." This creativity is bolstered by significant student engagement, particularly in initiatives that facilitate creation and experimentation. "When instructed to create tools, children exhibit enthusiasm," stated a teacher. Support from school administrators is a crucial element, as noted by an informant: "Our principal endorses teachers who wish to implement innovative methods." Nonetheless, certain external issues present significant impediments to the effective adoption of the STEM method. A significant barrier is the absence of training that especially addresses STEM integration in primary education. "We have not engaged in specialized STEM training," stated one educator. Moreover, educators encounter inadequate facilities and instructional resources, particularly in engineering and technology-oriented experimental or project endeavors. A teacher remarked, "At times, it is challenging to locate suitable tools or experimental materials." An additional challenge arises from the curriculum, as educators see a lack of suitable STEM-based teaching resources tailored to the peculiarities of elementary school education. A teacher remarked, "We still require examples of STEM-oriented instructional tools suitable for elementary education."

To address these restrictions, educators devise many adaptive tactics, including the simplification of thematic learning into projects that amalgamate aspects of science and mathematics. "I endeavor to transform thematic assignments into projects to enhance their realism for students," stated one educator. Collaboration among educators is a crucial method for both developing learning activities and exchanging ideas and practices. This is corroborated by the assertion, "Typically, we confer with other educators to generate activity concepts." These findings suggest that the potential for introducing STEM-based education in elementary schools is substantial, particularly with teacher innovation and active student engagement. This implementation necessitates systemic support through structured training, sufficient facilities, and relevant curricular standards to ensure optimal STEM integration in elementary school settings.

Table 2. Coding Analysis of Interview Results: Supporting and Inhibiting Factors for STEM Implementation

No.	Verbatim Quotes	Open Code	Axial Code (Category)	Theme
1	“We are used to making learning aids from used goods…”	Utilization of simple materials	Teacher creativity	Internal Supporting Factors
2	“If the children are asked to make tools, they are actually enthusiastic.”	Student enthusiasm in the project	Student engagement	Internal Supporting Factors
3	“Our principal supports teachers who want to try new methods.”	Support from school leaders	School initiatives	Internal Supporting Factors
4	“We have never participated in specific STEM training.”	No special training	Lack of professional development	External Inhibiting Factors

5	"Sometimes it is difficult to find appropriate tools or experimental materials."	Limited tools/media	Limited learning resources	External Inhibiting Factors
6	"We still need examples of STEM-based teaching tools that are suitable for elementary schools."	Need for contextual teaching devices	Lack of practical curriculum support	External Inhibiting Factors
7	"Usually we discuss with other teachers to find activity ideas."	Collaboration between teachers	Teacher adaptive strategies	Strategies for Facing Implementation Challenges
8	"I try to change thematic assignments into projects, so that they are more real for students."	Modification of thematic learning	Learning design adjustments	Strategies for Facing Implementation Challenges

DISCUSSION

The study's results reveal that teachers' and principals' perceptions of STEM-based learning are in the nascent phase of conceptual comprehension. Educators typically perceive STEM as a methodology that integrates science, technology, engineering, and mathematics through a sequence of contextual and engaging learning experiences. This comprehension is confined to a practical level and does not entirely include a thorough understanding of interdisciplinary integration and the orientation of scientific thought processes in STEM. This illustrates the epistemological issues identified in prior research, wherein educators acknowledge the significance of STEM yet encounter obstacles in its pedagogical implementation (Margot & Kettler, 2019; Samara & Kotsis, 2023). Teachers and principals in this survey exhibited a receptive and enthusiastic disposition towards the prospect of implementing the STEM method in elementary schools. This enthusiasm signifies a societal recognition of the significance of learning innovations that prioritize exploration, cooperation, and problem-solving. This finding aligns with research (Guerzon & Busbus, 2023) indicating that educators generally possess favorable attitudes of STEM integration, as it is deemed effective in enhancing student motivation and academic accomplishment. The endorsement of teacher initiatives by school administrators indicates the emergence of institutional readiness, despite the absence of explicit policies, professional training, or sufficient supporting infrastructure.

In this context, it is essential to position perception as a pivotal initial factor in the implementation of the STEM model at the primary school level. Chien & Chang (2023) propose that STEM integration should commence during pre-service teacher education and be reinforced through continuous professional development for current educators. This is significant given that inadequate infrastructure and insufficient training frequently constitute the primary barriers to the incorporation of technology and STEM in educational settings (Akram et al., 2022; Lechhab et al., 2023). Teachers expressed the necessity for practical examples of teaching materials and training to ensure they comprehend STEM ideas not only theoretically but also can effectively integrate them into lesson plans tailored to the characteristics of primary school kids. The study's findings indicated that thematic learning in elementary schools has indirectly facilitated the integration of STEM methodologies, particularly via project-based activities. While not formally organized as STEM education, certain activities conducted by pupils, like plant observations, the creation of measuring instruments, and

recycling initiatives, demonstrate an inherent integration of science, technology, engineering, and mathematics.

These approaches embody the fundamental concepts of Project-Based Learning (PBL), which emphasizes contextual learning and experiential engagement. This study aligns with (Anagün, 2018) perspective, which underscores that Problem-Based Learning (PBL) corresponds with constructivist theory by positioning students as active participants in the learning process through investigation and the resolution of real-world problems. Moreover, PBL has demonstrated efficacy in cultivating 21st-century competencies, including creativity, critical thinking, cooperation, and digital literacy (Ali et al., 2024; Puspitasari, 2020). The amalgamation of Project-Based Learning (PBL) inside the STEM educational framework is deemed effective in enhancing the pertinence of learning to quotidian experiences and fostering inventive thinking and problem-solving among students (Adikayanti & Retnawati, 2022; Al Fithri et al., 2025). This research validates that project-based learning employed by primary school teachers has the potential to be further developed and integrated into a more systematic STEM educational framework. According to (Denuga & Nkengbeza, 2022), the effective integration of STEM and PBL is significantly reliant on institutional support and the enhancement of teacher capacity via specialized professional training. Consequently, the current integrative methods may serve as a foundation for creating pertinent, adaptable, and contextually appropriate STEM models within elementary educational settings.

The execution of STEM-based education in primary schools is inextricably linked to the interplay of many internal and external factors that mutually influence one another. The study's findings indicate that teacher innovation, active student engagement, and principal support are essential foundational elements in fostering a conducive learning environment for STEM integration. Educators adapt thematic activities into straightforward projects pertinent to students' lives, and students exhibit considerable interest for activities that entail investigation, experimenting, or product development. The principal's endorsement of innovation and flexible learning environments indicates institutional preparedness. This conclusion aligns with the perspectives of (Ololade Elizabeth Adewusi et al., 2023) and (Gallagher et al., 2022), who underscore the significance of teacher adaptive capacity, namely the ability to modify learning tactics in response to students' needs and settings. Nonetheless, certain external impediments were also recognized. The limitations include inadequate facilities and infrastructure, such as technology gadgets and basic experimental tools, as well as a deficiency in professional training focused on STEM integration within the elementary school curriculum. Educators also indicated the lack of relevant curriculum requirements, hindering the methodical design of interdisciplinary learning. This aligns with the findings of (Kim, 2020), which indicate that the efficacy of teacher adaptation relies on sufficient knowledge, experience, and systemic support. In addressing these obstacles, educators formulate adaptive solutions, including collaboration with peers to create learning activities and engaging in reflection-based improvisation. Nonetheless, as noted by (Weddle et al., 2020), collaboration is insufficient without the enhancement of pedagogical ability and the provision of structural support.

Consequently, enhancing teacher competence is essential for promoting the efficacy of STEM integration. Educators must possess proficiency in educational technologies, cultivate 21st-century talents, and integrate character values throughout the learning process (Surtini & Muhtar, 2024). (Granziera et al., 2019) underscore that cultivating teachers' adaptive capacity during the pre-service phase is crucial for establishing resilient and pertinent learning in response to the dynamics of contemporary education. The advancement of STEM in elementary education necessitates not only curriculum and resources but also the cognitive preparedness and professionalism of educators as catalysts for change in the classroom. This study's findings underscore the necessity of creating a contextual, flexible STEM-based learning model that aligns with the cognitive development and learning traits of elementary school kids. This model must embrace a theme approach utilized in primary schools and incorporate the ideas of Project-Based Learning to foster critical thinking, problem-solving, and creativity in kids from an early age (Sah et al., 2024). Considering that educators have demonstrated capability in developing interdisciplinary activities, collaboration among instructors is a crucial element that must be promoted in model development. This aligns with the findings of (Nordgren et al., 2021), which indicate that collaborative planning can enhance the efficacy and durability of learning. This implication necessitates an active involvement from curriculum designers to create realistic and applicable integrative guidelines, alongside teacher training developers in formulating pedagogical capacity-building programs focused on STEM integration and proficiency in educational technology (Surtini & Muhtar, 2024). To enhance the validity and replicability of the model, additional research is essential, particularly studies conducted in varied contexts, to establish outcomes as a national benchmark for developing basic education that is responsive to 21st-century demands.

CONCLUSIONS

This study demonstrates that thematic and project-based learning in elementary schools had significant potential for evolution into a STEM-based learning model. Educators and administrators exhibited favorable views of the STEM methodology, while their comprehension remained broad and unstructured overall. Classroom learning approaches have incorporated components of science, technology, engineering, and mathematics that are contextually integrated, particularly through straightforward project assignments. Teacher inventiveness, student excitement, and support from school administrators are crucial internal supportive variables. Nonetheless, challenges were identified, such as inadequate facilities, insufficient professional training, and the lack of STEM-oriented curriculum standards suitable for the elementary school setting. In light of these findings, it is advisable to undertake the development and implementation of STEM learning models in elementary schools in a phased manner, taking into account the preparedness of educators and institutions. Enhancing teacher competence via specialized training, supplying supplementary learning materials, and implementing flexible curriculum design are essential prerequisites.

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