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The Role of Context in Problem-Solving in STEM Education: Bridging Informal and Formal Learning: A Systematized Literature Review

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Abstract

A common belief developed throughout human history that children learn principally in schools. The perspective that they are learning primarily in school is being increasingly challenged. Researchers have revealed that children develop content understandings in daily, out-of-school contexts, which often differ from what is taught in classrooms. This means that informal methods may not be taught in traditional school settings. Children often engage in informal settings outside of school while simultaneously dealing with school-taught algorithms and their ineffective application. Although formal school teaching methods may offer powerful tools to enhance cognitive processes, it is vital to comprehend how to effectively connect formal and informal STEM learning. Different strategies have been highlighted in the literature to connect abstract representations in formal learning to practical contexts in informal setups.
A substantial body of research has highlighted the differences and lack of connection between what students learn in school and what happens outside of school. This underscores the importance of analyzing and synthesizing the existing literature by leveraging extensive knowledge to identify the common trends and themes that have developed over time. Themes were developed using qualitative analysis techniques. This review sheds light on the significance of context in formal and informal learning in STEM problem-solving and highlights the strategies for bridging the contextual divide that exists between formal and informal learning environments. The significance of this review is to provide educators with practical implications by providing a theoretical refinement of the concept of formal and informal learning contexts in STEM problem-solving.

Keywords: formal learning, informal learning, mathematics, problem solving, engineering, STEM

Introduction

In 1985, Terezinha Nunes Carraher and colleagues challenged the perspective that students learn mathematics primarily in schools in their foundational research [1], broadening the scope of mathematics education research. This was one of the studies examining how real-world experiences systematically influence mathematical understanding. Their research revealed that children develop mathematical understandings in daily, out-of-school contexts, which often differ from what is taught in classrooms. Building on this, they investigated how informal, intuitive ways of learning mathematics can be leveraged in educational settings. Besides the cognitive and cultural dimensions of this research, their work spans the domains of children's literacy and numeracy with a special interest in educational applications.

While traditional classroom settings have been the primary focus of mathematical education research, a growing body of literature over recent decades highlights that mathematical learning and reasoning extend far beyond the confines of the classroom. Studies conducted outside formal educational settings reveal that both children and adults engage with mathematics in diverse, meaningful ways in their everyday lives, demonstrating practices that differ significantly from those found in traditional classrooms. Independent of formal schooling, mathematics serves as a vital tool for addressing real-world challenges and completing everyday and professional tasks [2],[3]. Researchers have underscored the potential of these informal experiences as valuable resources for enhancing mathematics education in schools. Martin and colleagues emphasize the need to bridge the divide between in-school and out-of-school mathematics, arguing that "when the mathematics of school and that of everyday life are seen as incommensurable, it impoverishes both contexts, separating the symbolic precision and power of school math from the flexibility and creative sense-making of everyday life" [4].

Mathematical practices and learning have been documented across a wide range of everyday contexts, including candy selling, carpet laying, video gaming, entertainment, sports, budgeting, money management, fishing, construction work, shopping, farming, sewing, professional industries, and family activities [5]-[15]. These informal experiences have been identified as critical predictors of children's developing math skills and knowledge. For example, Benigno [16] observed the natural mathematical practices of four-year-old African American children and their families, finding evidence of counting, geometric thinking, spatial reasoning, and discussions of difference and similarity. This growing recognition of the interplay between formal and informal mathematics learning underscores the importance of leveraging everyday mathematical experiences to inform and enhance classroom instruction.

In engineering education, much like mathematics, the integration of contextualized problems into the curriculum is essential for bridging the gap between theoretical knowledge and real-world application. Wolff [34] emphasizes the importance of contextualizing engineering problems to enhance problem-solving abilities in complex, real-world settings. According to Wolff [34], the theory-practice divide in engineering can be addressed by incorporating multiple perspectives, specifically situational, doctrinal, and purist insights, into problem-solving tasks. In this way, students are encouraged not only to apply disciplinary knowledge but also to recognize the contextual complexities that influence engineering practice in professional environments.

This study synthesizes existing literature on the differences and lack of connection between STEM concepts learned in school and outside of school, identifying common trends and themes that have developed over time. It is vital to comprehend how to integrate formal and informal engineering, mathematics, and science learning through effective pedagogical strategies. This review synthesized the research on the significance of context in formal and informal learning in problem-solving and highlighted the strategies for bridging the contextual divide that exists between formal and informal learning environments, and suggested future directions.

Research Questions

By reviewing the available literature, this systematized literature review aims to answer the following research questions:

1) How does context influence formal and informal learning in STEM education?
2) What are the pedagogical strategies to integrate informal learning in formal educational settings?

Methodology

To address the research questions, a systematic literature review was conducted to examine the existing body of work methodically. The groundbreaking work of Carraher and colleagues [1] has since influenced numerous studies in mathematics education, shaping the current understanding of learning in context. This synthesis examines articles and demonstrates how the study findings have contributed to more practical, context-based approaches in mathematics education, fostering deeper connections between real-world problem-solving and classroom learning.

Articles were purposefully selected based on specific inclusion and exclusion criteria. A codebook was created to document the selected articles, enabling a thorough analysis of each study's objectives, sample characteristics, data collection methods, results, implications, and limitations, as well as to establish preliminary connections aligned with our research questions. The findings were synthesized using the systematic thematic synthesis method outlined by Booth et al. [17] and communicated through a narrative description. Thematic analysis was used for developing themes [18].

Search and Selection Criteria

After using various search strings derived from the central theme of the literature review to identify relevant articles across multiple databases, ERIC, IEEE Xplore, Education Full Text, PsycINFO, and Google Scholar, we selected only two databases of ERIC and PsycINFO, to run the initial search. Multiple search strings were built by taking all the possible combinations of search keywords. Each string is made with the union and intersection of the key concept categories: formal learning, informal learning, context, mathematics, and engineering. Multiple search strings like the one mentioned below were formed to extract an extensive collection of literature while maintaining the simplicity of search terms.

("formal learning" OR "informal learning ") AND ("Math's" OR "mathematics" OR "engineering" OR "science" OR "technology") AND ("problem solving")

We retrieved 44 articles from ERIC and 37 from PsycINFO that included the search terms appearing anywhere within the title, abstract, or full text. Initially, the articles were screened based on keywords in the title and abstract. Then the selected articles were screened further by reviewing the full text to ensure their relevance. The criteria for inclusion in the review were as follows: (1) *publication type*- the publication was a journal article or conference paper, (2) *empirical*- the study reported empirical findings, (3) *participants*- K-12 and STEM students, (4) articles published after Carraher et al.'s [1], (5) *language*- the study was written in English. Studies were excluded if they did not answer the research questions. We chose to synthesize the eighteen relevant articles based on the inclusion and exclusion criteria and relevance based on the research questions. The selected articles were marked with an asterisk in the reference section. Articles were reviewed to document each study's objectives, results, and outcomes, facilitating preliminary connections with the research questions. Subsequently, a second review was conducted to record sample characteristics, study purpose and focus, and research design features of the selected articles. These two sets of coding elements were consolidated into a unified coding table, which was periodically updated as needed and treated as a dynamic document.

Synthesis Method

A thematic analysis was conducted to identify key themes across the studies listed in the coding table. This method, inspired by Booth et al. [17], was utilized to extract common ideas and conclusions pertinent to our research questions, rather than to generate new knowledge, though that remains a possibility. This systematized literature review synthesizes the relevant studies from the coding table, aligning them with our research questions to present the key findings.

Analysis

Themes were developed across the array of selected studies using the thematic analysis method of Saldana [18] by extracting common ideas and conclusions related to our research questions. Two rounds of coding were performed to develop the themes. In the first cycle, the findings of the selected articles were coded using descriptive coding relevant to our research questions. In the second phase, the codes were grouped into categories and themes to synthesize the findings of the included studies into meaningful ideas.

Findings

The analysis of eighteen studies included in this synthesis resulted in four key themes: cognition in context, spatial context, transfer of learning, and pedagogical strategies.

Theme 1: Cognition in Context

Cognition in context refers to the idea that thinking, learning, and problem-solving are not isolated mental processes but are shaped by the environments in which they take place. This means that knowledge and skills are often developed in response to the specific demands and social interactions of a given context. This theme was developed to answer the first research question and runs through the studies published after Carraher et al.'s research, illustrating the central role of context in shaping cognitive development. Carraher et al.'s [1] study on Brazilian street vendors identified a clear disconnect between the informal math skills developed through daily activities and the formal procedures taught in academic settings, indicating that traditional school math fails to leverage the practical knowledge gained from everyday experiences. The findings underscored the importance of recognizing that cognitive skills are highly context-dependent, as students perform better in meaningful situations rather than in abstract form. Street vendors use strategies that involve mentally manipulating quantities for daily problem-solving tasks. In contrast, school settings emphasized the manipulation of symbols for computations. Resnick [21] took Carraher et al.'s findings and highlighted the need to rethink schooling as it focuses on individual performance and promotes symbolic thinking, whereas mental activities out of school engage directly with objects and situations. Resnick argued that school learning is decontextualized, isolating knowledge from real-world contexts, and tends to focus on isolated cognitive tasks, whereas real-life cognition is deeply rooted in contexts [21]. Saxe [15] extended Carraher et al.'s and Resnick's emphasis on the importance of context in mathematical learning. He examined the mathematical understanding of child candy sellers through their participation in selling. Saxe's study emphasized that children's mathematical skills are heavily influenced by their everyday experiences, social interactions, and the practical demands of their environment, but these skills do not always transfer smoothly to formal educational settings. These studies highlighted the concept of cognition in context in a way that children's cognitive skills are shaped by their practical experiences and environments. The math skills demonstrated by street vendors in Carraher et al.'s study and candy sellers in Saxe's study are highly effective within their specific real-world contexts, but transferring these skills to formal education remains a challenge, as argued by Resnick for a restructuring to better reflect the social and practical nature of cognition.

Engineering education is undergoing rapid transformation, with cognitive perspectives on learners taking center stage in shaping teaching methodologies. This shift highlights the significance of psychological factors and social interactions as key elements in the learning process. It also underscores the value of students' prior knowledge, the impact of context on their learning experiences, and the widely accepted notion that learners actively construct their understanding of subject matter. Kipper and Rüütmann [35] emphasized how learning in engineering education is deeply influenced by the interplay between cognitive processes and contextual factors. Their research underscores that cognition in engineering education is not merely about understanding abstract concepts but is deeply rooted in the context in which learning occurs. By incorporating real-world applications, social interactions, and students' prior knowledge, the teaching process fosters a more holistic and meaningful cognitive development.

Brizuela and Strachota [20] grasped these foundational ideas a step further by integrating the concept of playful engagement into early algebraic reasoning by emphasizing the role of real-world contexts in mathematical learning. Where Carraher et al. [1] focused on how informal contexts shape mathematical understanding, Brizuela and Strachota [20] expand this by creating a familiar contextual environment where students engage in playful stances towards algebra. This demonstrates that when students' math learning is tied to meaningful and familiar experiences (like candy sharing or playful tinkering), they experience cognition in context more naturally, facilitating deeper learning.

Integrating informal methods with formal procedures can significantly enhance mathematical understanding. This approach allows learners to connect intuitive problem-solving strategies with structured mathematical concepts, fostering a deeper comprehension of the subject matter. In the study by Hattikudur et al. [25], participants were introduced to two distinct methods for solving systems of equations: an informal "trading" procedure and a formal "matrix" procedure. They examined how comparing informal and formal procedures affects learning in solving systems of equations. Similarly, Civil [5] provides valuable insights into how integrating everyday mathematics with formal mathematical instruction influences student engagement and learning. She demonstrated that when classroom activities connect with students' real-life experiences, participation increases, especially among those who might otherwise disengage. However, as discussions shift toward more formal mathematical concepts, some students may withdraw, highlighting the need for careful integration of informal and formal learning to maintain engagement.

Kaminski and Sloutsky [26] discussed how the context in which mathematical concepts are presented can significantly influence children's learning and cognitive processing. Specifically, they examined the impact of using rich, contextualized materials (like colorful, student-made paper pizzas) versus simple, generic materials (such as monochromatic paper circles) in teaching fractions to first-grade students. They highlighted that the cognitive demands of interpreting and creating complex, context-rich materials can interfere with the effective learning of mathematical ideas. Therefore, introducing mathematical concepts with simple, generic materials may be more beneficial for elementary students' comprehension and application of these concepts. Similarly, Pouw et al. [29] embedded cognition emphasizes the dynamic interplay between a learner's cognitive processes and their physical environment. They argued that the environment can act as an extension of the mind, offloading cognitive demands and shaping problem-solving strategies. For example, external artifacts, such as instructional manipulatives, can structure cognitive activities by reducing working memory load and offering direct sensory and motor engagement. This view suggested that cognition is not isolated within the brain but distributed across tools and spaces, which makes the learning context crucial for facilitating understanding. The research highlighted the importance of designing learning environments that integrate perceptual and interactive richness to align with how cognition naturally unfolds in context.

Zbiek and Conner [31] discussed mathematical modeling that enables the application of mathematical principles to address real-world problems. Mathematical modeling situates learning within meaningful real-world contexts, allowing students to see the relevance of abstract mathematical ideas. This contextualization engages cognitive processes by requiring learners to interpret, analyze, and adapt to the constraints and dynamics of a given situation. The theme of cognition in context permeates all aspects of STEM education, emphasizing that learning is not an isolated mental activity but deeply influenced by the environments and experiences in which it occurs. Across STEM disciplines, whether in engineering design, mathematical reasoning, or scientific inquiry, students engage more effectively when knowledge is connected to meaningful, real-world contexts.

Theme 2: Spatial Context

The spaces we inhabit and learn in significantly influence our understanding and experience of the world. Most research in mathematics teacher education has focused on cognitive and social concepts. However, discussions often overlook the importance of physical and imagined spaces. Recent studies in mathematics and STEM education highlight an increasing need to comprehend the significance of spatial reasoning within the mathematics curriculum and its application in daily spatial interactions [27].

The environment in which we learn mathematics affects how we learn it and what we perceive as mathematics [1]. Carraher et al. demonstrated that Brazilian street vendors excelled at practical math skills within the spatial context of the marketplace. The findings of Carraher et al. [1] significantly influenced Weiland and Poling's [23] research by reinforcing the critical importance of spatial context in mathematics education. Weiland and Poling echoed this by encouraging teacher education programs to integrate spatial contexts into their curricula, helping future teachers create lessons that connect mathematics to students' lived experiences. This alignment between theory and practice supports the notion that effective math education must engage with the real-world contexts of students. They advocated preparing teachers to consider various environments that can help students see connections across the curriculum, making math more relevant to their lived experiences. They suggested modifying classroom activities like classroom observations, community walks, and data investigations to incorporate spatial considerations into their practice.

Weiland and Poling's approach of utilizing community walks directly connects to Saxe's findings by allowing future teachers to observe how spatial contexts affect student learning and interaction with mathematics. This can help teachers recognize the importance of incorporating students' environments into their instruction. The incorporation of spatial considerations into teacher education, as suggested by Weiland and Poling, complements Wood's findings by encouraging future teachers to create learning environments that facilitate collaboration and discussion. By modifying activities to reflect spatial contexts, educators can better support student engagement and understanding. Weiland and Poling [23] and Brizuela and Strachota [20] shared emphasis on the importance of spatial considerations in mathematics education. While Weiland and Poling focused on the physical and geographical spaces in which students learn, Brizuela and Strachota [20] emphasized the cognitive development of spatial reasoning within those spaces. Together, these works suggested that effective mathematics education must address both the external environments students inhabit and the internal cognitive tools they use to understand and interact with those environments. These studies emphasized that learning is deeply intertwined with the environments in which it occurs, suggesting that educators must recognize and adapt to these contexts to enhance students' understanding and engagement in mathematics. Viewing space as a dimension of reality goes beyond content or teaching methods, breaking down the artificial boundaries between subjects and giving students the chance to see connections across the curriculum.

Courtney et al. [28] brought the concept of field trips as spatial contexts to enhance student learning, particularly in mathematics. Field trips provide opportunities for students to interact with real-world environments that are rich in mathematical content, such as museums, architectural landmarks, and other community spaces. These experiences help ground abstract mathematical concepts in tangible, meaningful contexts, allowing students to develop problem-solving skills through inquiry-based learning. For instance, the study emphasizes that field trips enable students to explore mathematical problems embedded in community settings, such as calculating dimensions or interpreting spatial layouts, fostering a connection between mathematical reasoning and real-world applications.

Besides physical, research has also emphasized the virtual spaces besides physical that can enhance the problem-solving skills and conceptual grips. The study by Demitriadou et al. [30] emphasizes that VR and AR improve students' spatial skills by enabling them to visualize and manipulate 3D geometric shapes, fostering a deeper understanding of spatial relationships. The activities encouraged students to identify geometric shapes in their surroundings, reinforcing the relevance of spatial geometry to daily life. By providing an immersive and interactive experience, these technologies make abstract spatial concepts more tangible and engaging, aiding cognitive and psychomotor development related to spatial contexts. The study concludes that both VR and AR technologies are equally effective in enhancing STEM learning, particularly in the spatial domain, by making concepts more accessible and engaging compared to traditional teaching methods.

Avargil et al. [38] used spatial context primarily through interdisciplinary connections in the Taste of Chemistry module. Teachers focused on transferring between molecular representations, such as 2D structural formulas, and 3D models like ball-and-stick or space-filling models. Four levels, including macroscopic (observable phenomena), microscopic (particle-level explanations), symbol (equations and graphs), and process (reactions and transformations), are integrated into teaching. These transitions help students connect symbolic and spatial aspects of chemistry. These approaches collectively aim to deepen student understanding by bridging abstract concepts with spatially tangible representations.

Theme 3: Transfer of Learning

The concept of transfer of learning refers to the ability to apply knowledge and skills learned in one context to new, different situations. Saxe [15] explored the concept of learning transfer through candy selling by building on Carraher's insight that transfer of learning can be bidirectional, informal math skills can be adapted for formal educational contexts, and formal strategies can be adjusted for real-world situations. However, Saxe's research findings revealed that there was a gap in the accuracy of solutions, indicating limited generality and requiring specialized strategies that reflect a deeper understanding of how to navigate across formal and informal contexts.

Resnick's [21] theoretical research, prompted by the empirical findings of Carraher et al [1] explained the disconnect between formal and informal learning in mathematics in terms of a mental model. Mental models support the transfer of learning by permitting flexibility in response to unexpected situations. Resnick emphasized the importance of schooling in equipping students with the cognitive tools, like mental models, needed to construct relevant mental models for diverse situations, enabling them to adapt their skills effectively when faced with new environments or unexpected problems. If schools continue to prioritize individual competence, tool-free performance, and decontextualized skills, educating students solely for success in school may not sufficiently prepare them to be effective learners outside of the classroom [21].

Wood [24] explored the development of mathematical understanding by creating opportunities for argument and discussions in the classroom, replicating informal learning benefits within a formal setting. She argued that incorporating more real-life, practical problems into classroom discussions, like the types of problems encountered in Carraher et al.'s study, can make the classroom a place where formal and informal thinking can co-exist. Wood's research was set in a dynamic, argument-driven classroom, using open-ended, discussion-based problems. The setting was deliberately designed to promote social interaction and cognitive engagement through discourse, allowing students to deepen their understanding of mathematical concepts and practice applying their learning flexibly. The problems were real-world or contextualized scenarios that students could relate to, which helped to bridge the gap between abstract mathematical concepts and practical application.

Unlike Carraher et al.'s and Saxe's findings, where transfer from informal to formal settings was problematic, Wood's classroom environment nurtured cognitive flexibility that aids transfer by encouraging students to articulate, debate, and justify their reasoning in a structured yet socially interactive setting.

Brizuela and Strachota [20] provided a potential solution, just like Wood's research presented in the form of classroom discourse, to the problems discussed in Carraher et al.'s and Saxe's research regarding the difficulty of transferring knowledge from one context to another. They suggested joyful engagement in algebraic tasks can create a smoother bridge for the transfer of learning by making abstract concepts more engaging and accessible. When students experience joy and agency in solving algebraic problems, they are more likely to retain and transfer these skills to other contexts, indicating that positive emotional engagement enhances learning transfer, as also suggested in Wood's and Saxe's findings. The use of familiar contexts, multiple representations, and open-ended questions encouraged students to think deeply about the underlying principle of algebra, making it easier for them to transfer their learning to new tasks [20]. Zbiek and Conner [31] extended the concept of learning transfer to mathematical modeling differs from mental models suggested by Resnick [21]. Mathematical modeling serves as a rich context for learning by bridging the real-world and mathematical worlds, fostering spatial reasoning, and enabling learning transfer. It encourages students to explore, connect, and deepen their understanding of mathematical ideas, emphasizing both cognitive development and practical application.

The use of contextualized learning environments enhances transfer, but Kaminski and Sloutsky [26] indicated that highly perceptual materials may hinder abstraction. They conducted two experiments to examine whether different instructional approaches impacted students' ability to transfer fraction knowledge to novel contexts. They discussed learning transfer in the context of using rich, contextualized, student-made material versus simple, pre-made material for teaching fractions to elementary students. The findings suggested that the type of material used in instruction significantly affects learning transfer. Transfer was measured by testing students' ability to apply learned fraction concepts to novel tasks one week after the initial instruction. The study concluded that rich, perceptually detailed materials may hinder transfer because they introduce extraneous information that distracts from the core mathematical relations.

Theme 4: Pedagogical Strategies

The articles following Carraher et al. [1] presented several pedagogical strategies that can enhance mathematics education by incorporating cognition in context, learning transfer, and spatial context, focusing on students' learning processes. This theme is developed to answer the second research question. Weiland and Poling [23] advocated for a spatial turn in mathematics teacher education, encouraging teachers to recognize and utilize the spatial dimensions of learning environments. Educators can implement activities that explore spatial reasoning, such as mapping exercises, geometry projects, or community walks that allow students to analyze and visualize mathematical concepts in their surroundings. Wood's [24] research highlighted the effectiveness of collaborative discourse in the classroom based on real-world problems to move their mental effort from contextual understanding to a more abstract or formal understanding of math itself. Besides contextual discourse, Brizuela and Strachota [20] encouraged the use of visual tools showing real-world scenarios, allowing students to explore ideas with joy and curiosity, making learning more meaningful and applicable to their lives. Resnick's [21] shifted the idea from visual tools towards the focus on mental models, a key part of her pedagogical strategy, as it promotes deep learning, flexibility, and the ability to transfer knowledge across different contexts, and educators can support learners in understanding mathematical systems more holistically. By encouraging teachers to recognize how spatial contexts influence student learning, Weiland and Poling

[23] advocate for more equitable, engaging, and contextually relevant math education that connects students to the physical world and its spatial dynamics.

The use of concrete and digital mathematical models by teachers to present problems in context-based situations emerged as one of the most common strategies identified as a theme. Zaranis et al. [32] discussed the incorporation of Realistic Mathematical Education (RME) principles, which emphasize using thematic frameworks drawn from real-life scenarios. Digital tools, such as tablets and mobile applications, play a pivotal role in this process by offering interactive activities that simulate real-world problem-solving. For example, children might calculate the number of tickets required to enter a park or solve addition problems based on groceries in a basket. These tasks contextualize mathematics, enhancing students' ability to relate abstract numbers and operations to tangible experiences. Additionally, combining digital activities with physical resources such as board games and hands-on manipulatives reinforces these connections, catering to diverse learning styles. Immediate feedback from digital tools further supports student understanding by allowing them to refine their problem-solving strategies in real-time. Besides this, Zbiek and Conner [31] provided a diagrammatic model of mathematical modeling that illustrates how mathematical understanding can emerge or evolve as learners work through modeling tasks. It fosters a dynamic interplay between context and abstraction, ensuring that the mathematical framework not only simplifies reality but also retains its essential complexities to provide actionable insights. Similarly, De Corte et al. [33] argued that traditional mathematics education often fails to encourage realistic modeling in problem-solving, leading to what they term a suspension of sense-making. Their findings emphasize the importance of embedding mathematical problems within authentic, real-world contexts to foster meaningful engagement and practical application of mathematical concepts.

The incorporation of context-based approaches is also being emphasized in STEM education. Kipper and Rüütmann [35] emphasized the Inductive Model as a primary method for introducing context into learning and teaching in engineering education. This model begins with specific examples**,** such as real-world problems, case studies, or experimental data, and guides students to analyze and extract general principles or concepts. By focusing on real-world scenarios, the Inductive Model immerses students in the complexities and contextual realities of engineering, enabling them to construct their understanding rather than passively absorbing information. In another study by Fadhilah et al. [36], the context in physics education, primarily through the application of the Contextual Teaching and Learning (CTL) approach, is introduced. The contextualization of learning materials is emphasized to help students understand the relevance of physics to their daily lives, professional goals, and societal needs. The CTL approach can transform physics education by linking abstract concepts to practical, real-world applications. This approach not only improves students' comprehension and motivation but also fosters critical thinking, creativity, and a deeper understanding of physics as the foundation of engineering [36].

Sutaphan and Yuenyong [37] provided a **s**even-stage framework that begins with identifying social issues, such as environmental challenges or technological design, and progresses through exploring solutions, acquiring necessary knowledge, decision-making, prototyping, testing, and socialization. This context-based approach fosters inquiry and constructivist learning, encouraging students to connect academic concepts to practical applications. By combining conceptual (scientific and mathematical) and procedural (design and modeling) knowledge, students develop problem-solving skills, creativity, and an understanding of technology's impact on society, making STEM education more relevant and engaging.

Discussion

This review concludes by synthesizing the results of eighteen key articles with the foundational research of Carraher et al. [1], highlighting influential themes that have shaped STEM education research. The role of context is emphasized by a pool of scholars [20]-[40], including Saxe, Resnick, Wood, Weiland and Poling, and Brizuela and Strachota, who all expanded on the idea that engineering and mathematics learning is deeply influenced by the physical and social environments in which it occurs. Carraher et al.'s study has provided a dynamic lens through which researchers have examined how cognition in context, learning transfer, and spatial context impact mathematics learning and teaching. These themes illuminate both the challenges and opportunities inherent in enhancing STEM learning experiences. The theme of cognition in context suggested that integrating real-world scenarios and informal problem-solving methods into formal curricula can foster holistic cognitive development and bridge the gap between theory and practice. Incorporating spatial contexts, such as community walks or field trips, into teachers' education to connect mathematical concepts to students' lived experiences. Educators should consider incorporating field trips and VR/AR technologies into their teaching strategies to enhance students' spatial skills. By providing tangible experiences and opportunities to interact with and visualize abstract STEM concepts, these approaches can make learning more meaningful and engaging, ultimately supporting deeper conceptual understanding and improved problem-solving abilities. The gap between formal and informal can be bridged by incorporating both physical spaces and cognitive tools, educators can better support students in understanding mathematical concepts and their real-world applications. These approaches also align with broader goals of equity in STEM education, ensuring that diverse learning needs are met.

The difficulty students face in transferring skills learned in informal settings to formal education emphasizes the need for context-based models that bridge these gaps. The strategies of collaborative discourse and joyful engagement to facilitate transfer can nurture cognitive flexibility. Mathematical modeling, which situates learning in real-world contexts, fosters both cognitive development and practical application. The Inductive Model and the Contextual Teaching and Learning (CTL) approach discussed by Fadhilah et al. [36], emphasize real-world applications and constructivist learning principles. Instructors should implement these strategies to encourage students to actively construct knowledge through inquiry, reflection, and problem-solving in meaningful contexts. Sutaphan and Yuenyong's [37] seven-stage framework further illustrates how STEM education can integrate social issues and practical applications, fostering critical thinking and creativity. Digital tools and interactive activities, as explored by Zaranis et al. [32], also play a pivotal role in contextualizing learning, making abstract concepts more accessible and engaging for diverse learners. For educators, incorporating such strategies is critical in helping students move beyond rote learning to constructing knowledge through context-based learning.

Conclusion

The integration of context into STEM education is vital for fostering deeper cognitive engagement, improving learning transfer, and enhancing spatial reasoning. By grounding abstract concepts in real-world scenarios and leveraging innovative pedagogical strategies, educators can create more meaningful and inclusive learning experiences. It will be helpful for diverse learners by providing them with cultural and socially relevant experiences. However, challenges such as bridging the gap between informal and formal learning and ensuring effective teacher collaboration remain. Future research should continue to explore these intersections, with a focus on refining instructional approaches to better align with the cognitive and contextual realities of learners in diverse educational settings.

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