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LEARNING MATHEMATICS IN COMPUTER SCIENCE COURSES: A COMPREHENSIVE STRUCTURED REVIEW

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Abstract:

Mathematics underpins computer science education, fostering analytical thinking, logical reasoning, and proficient problem-solving abilities. Many students in computer science courses, however, find it challenging to perceive its applicability, which might impede engagement and learning outcomes. This work fills this gap by conducting a systematic review of recent literature on mathematics learning in computer science contexts. Following the PRISMA procedure, a systematic search was performed in two principal databases, Web of Science and Scopus, resulting in 21 primary studies that fulfilled the inclusion criteria. The results were consolidated into three theme categories: technology-enhanced mathematics education, integration of programming and computational thinking, and curriculum and pedagogical innovation. Findings demonstrate that methodologies such as adaptive learning platforms, augmented reality, and flipped classroom models not only improve conceptual comprehension but also elevate student motivation. The study emphasises the necessity of correlating mathematical knowledge with actual programming applications, while also considering learner-related aspects such as motivation, self-efficacy, and mathematics fear. Facilitating fair resource access and integrating mathematics effectively into computer science programs helps

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prepare graduates with the necessary technical skills and agility to succeed in a swiftly changing digital environment.

Keywords:

Computer Sciences, Learning, Mathematics

Introduction

Mathematics is a fundamental component of computer science education, playing a crucial role in the development of future IT professionals. The integration of mathematical concepts into computer science courses not only supports the understanding of core computing principles but also enhances critical thinking, logical reasoning, and problem-solving skills, which are essential competencies for any IT professional (Bruce et al., 2003; Sirakova & Sirakov, 2025). The ability to abstract and model real-world problems mathematically is vital for designing, specifying, coding, and verifying software solutions across various domains such as banking, e-commerce, and airline reservations (Bruce et al., 2003). Furthermore, mathematics serves as the lingua franca of modern science due to its conciseness and abstractive power, making it indispensable for proving theorems and fostering computational thinking (Benzmüller et al., 2010).

Effective pedagogical strategies are essential for teaching mathematics within computer science courses, especially given the challenges students often face with the subject (Allison, 2021). Innovative approaches such as the flipped classroom model, where students learn new content outside of class and engage in problem-solving and discussions during class, have shown promise in enhancing student engagement and understanding (Allison, 2021). Additionally, integrating mathematical thinking into the computer science curriculum through courses like discrete mathematics and functional programming can make the relevance of mathematics to programming and software development more evident (VanDrunen, 2017). These strategies not only improve students' mathematical competence but also support better learning and programming practices (Setzer, 2009).

The design of computer science curricula must emphasize the importance of mathematics to ensure students appreciate its relevance and application in computing (Whalley et al., 2020). Courses that integrate mathematical concepts with computer science, such as those focusing on neural network methods for solving differential equations, provide students with a deeper understanding and appreciation of both disciplines (Farjudian, 2023). Moreover, the flexibility of the curriculum to accommodate students' evolving beliefs about mathematics and its connection to their career inclinations is crucial for fostering a positive attitude towards the subject (Sigurdson & Petersen, 2017; Whalley et al., 2020). By aligning mathematical education with computational skills and interdisciplinary research, educators can cultivate a robust scientific worldview and continuous self-education among students (Boronenko & Fedotova, 2023).

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Table 1: Summary of Literature Review

Aspect	Findings
Importance of Mathematics	Enhances critical thinking, logical reasoning, and problem-solving skills; vital for software design and verification (Benzmüller et al., 2010; Bruce et al., 2003; Sirakova & Sirakov, 2025)
Pedagogical Strategies	Flipped classroom model improves engagement; integration of discrete mathematics and functional programming enhances relevance (Allison, 2021; Setzer, 2009; VanDrunen, 2017)
Curriculum Design	Emphasizes the relevance of mathematics; integrates interdisciplinary research; aligns with career inclinations (Farjudian, 2023; Sigurdson & Petersen, 2017; Whalley et al., 2020)
Student Perceptions	Students appreciate mathematics more when its relevance to computer science is clear; a flexible curriculum supports evolving beliefs (Sigurdson & Petersen, 2017; Whalley et al., 2020)
Innovative Approaches	Game-based learning and interactive classroom environments enhance student performance and engagement (Enriquez, 2008; Naik, 2017)

This structured approach ensures that the introduction and summary of the literature review provide a comprehensive overview of the role and importance of mathematics in computer science education, supported by evidence from the provided abstracts that can be viewed in Table 1.

In conclusion, Figure 1 presents a concept map that outlines the foundational framework for the topic "Learning Mathematics in Computer Sciences Course." The map is organized into three primary domains: Applications in Computer Science, which includes real-world implementation areas such as Cellular Automata, Networks, Nurse Rostering, and Chaos Theory; Mathematical Concepts, encompassing essential theoretical elements like Fractals and Algorithms; and Course Structure, which highlights the educational framework through components such as Curricula and Course Outline. Together, these interconnected themes emphasize the multifaceted relationship between mathematical understanding and its application, delivery, and relevance within the field of computer science education.

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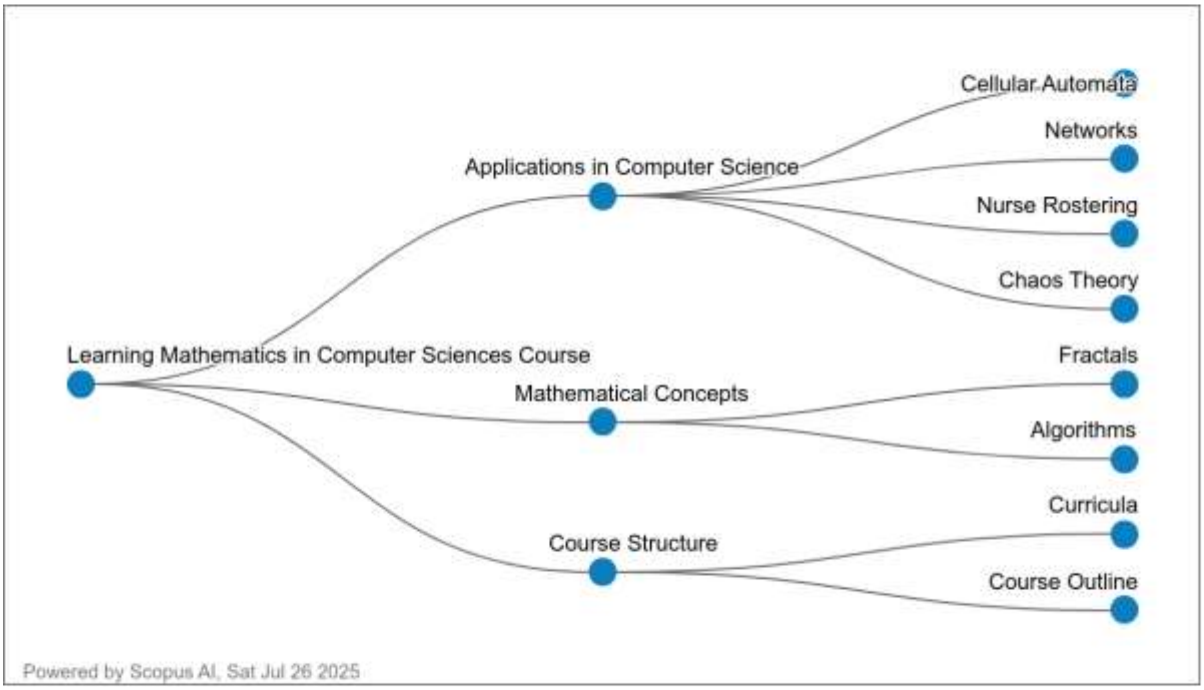

Figure 1: Concepts Map for the Introduction of Learning Mathematics in Computer Sciences Course

(Source: Powered by Scopus AI, Sat Jul 26 2025)

Literature Review

Learning mathematics in computer science courses is essential for building strong analytical and problem-solving skills, as well as for understanding the foundations of modern technologies like artificial intelligence and data science. Integrating mathematics with computer science helps students see the relevance of mathematical concepts and prepares them for real-world challenges in the tech industry.

Enriching the Curriculum

Combining computer science courses with traditional mathematics curricula addresses gaps between abstract mathematics and practical applications. This integration stimulates student engagement, participation, and innovation, providing both theoretical and practical knowledge needed for current industry demands, especially in areas like data science and machine learning (Anthony et al., 2019; Kao, 2021; Matthews et al., 2020).

Teaching Approaches and Student Experience

Introducing theoretical computer science concepts, such as computability and algorithmic complexity, early in mathematics courses improves students' motivation and performance in advanced subjects. Leveraging students' strengths in coding and using computational tools, like Jupyter notebooks, transforms their view of mathematics from a set of rigid steps to a creative, exploratory process. This approach encourages resilience and a deeper understanding of mathematical ideas (Castle, 2023; Del Vado Vírseda, 2021; Friend et al., 2023).

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Mathematics as a Foundation for Computer Science

Mathematics is fundamental to computer science, supporting analytical thinking and providing the basis for key topics such as binary systems, Boolean algebra, calculus, discrete mathematics, linear algebra, number theory, and graph theory. These areas are especially relevant with the rise of machine learning, artificial intelligence, and related fields (Reddy, 2025; Sotelo et al., 2024; Yadav, 2021).

Modernization and Technology in Learning

The use of technology, such as eLearning platforms, makes mathematical concepts more accessible and can increase motivation and competence among computer science students. Modernizing the mathematics curriculum ensures it remains relevant to the evolving needs of computer science (Andini et al., 2018; Anthony et al., 2019).

As a conclusion, integrating mathematics into computer science courses enhances student engagement, deepens understanding, and equips learners with the skills needed for today's technological landscape. Innovative teaching methods and curriculum design are key to making mathematics meaningful and accessible for computer science students.

Material and Methods

Methods used in this systematic review are based on Page et al. (2021), that have several steps as below:

Identification

This study employed crucial phases of the systematic review methodology to gather a substantial quantity of relevant resources. The initial step in the procedure was selecting keywords. Subsequently, dictionaries, thesauri, encyclopaedias, and prior research were employed to identify analogous phrases. Search strings were developed for the Web of Science and Scopus databases after identifying all relevant phrases (refer to Table 2). During the initial phase of the systematic review, 587 pertinent papers were identified across the three databases

Table 2: The Search String

Database	Search String
Scopus	TITLE-ABS-KEY (Learning AND Mathematic AND Computer) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (PUBYEAR , 1982) OR EXCLUDE (PUBYEAR , 1992) OR EXCLUDE (PUBYEAR , 1996)) Date of Access: August 2025
WoS	Learning AND Mathematic AND Computer (Topic) and Article (Document Types) and English (Languages) Date of Access: August 2025

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Screening

During the screening phase, relevant research items are assessed for their conformity with the established research question(s). This process often entails selecting relevant subjects for the Learning Mathematics in Computer Sciences Course and eliminating duplicates. Initially, 421 publications were eliminated, resulting in 166 papers for subsequent evaluation according to predefined inclusion and exclusion criteria (see Table 3). The primary inclusion criterion was literature, seen as the essential source of practical insights, comprising reviews, meta-syntheses, meta-analyses, books, book series, book chapters, and conference proceedings not featured in the most recent study. Only English-language publications from 2002 to 2025 were considered. Twenty-one publications were excluded due to duplication.

Table 3: The Selection Criterion of Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2002 – 2025	< 2002
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press

Eligibility

During the third phase, known as the eligibility stage, 145 papers were chosen for comprehensive evaluation. The titles and primary text of each article were meticulously examined to confirm their relevance to the inclusion criteria and consistency with the study objectives. Consequently, 124 papers were omitted due to factors such as being beyond the research topic, possessing irrelevant titles or abstracts, or lacking full-text access to empirical data. In conclusion, 21 papers were considered appropriate for the ensuing review.

Data Abstraction and Analysis

This study utilised an integrative analysis as an evaluative tool to examine and synthesise several research designs (quantitative methodologies). The aim of the comprehensive investigation was to identify relevant topics and subtopics. The data collection phase was the preliminary step in the theme's development. Figure 2 depicts the authors' comprehensive examination of a collection of 21 publications about claims or material relevant to the topics of the current study. The authors subsequently evaluated the predominant research in mathematics education. The methodology utilised in all studies and the research outcomes are currently under scrutiny. The author later collaborated with co-authors to develop themes based on the outcomes of this study. A log was kept throughout the data analysis process to record any analyses, viewpoints, questions, or other reflections relevant to data interpretation. The authors ultimately analysed the outcomes to detect any anomalies in the theme design process. Any differences between the concepts are discussed among the authors. The authors also examined the results to rectify any discrepancies in the theme development process. If any differences on the themes arise, the authors will confer among themselves. The formulated notions were polished to ensure coherence. To verify the validity of the issues, we propose three questions as detailed below:

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1. How do technology-based tools and digital learning environments influence students' understanding, engagement, and performance in mathematics across various educational levels?
2. What are the impacts of incorporating programming and computational thinking into mathematics instruction on students' problem-solving abilities and cognitive growth?
3. What is the effect of integrating ICT and gamification in flipped classrooms on student engagement and learning outcomes?

International Journal of Education, Psychology and Counseling
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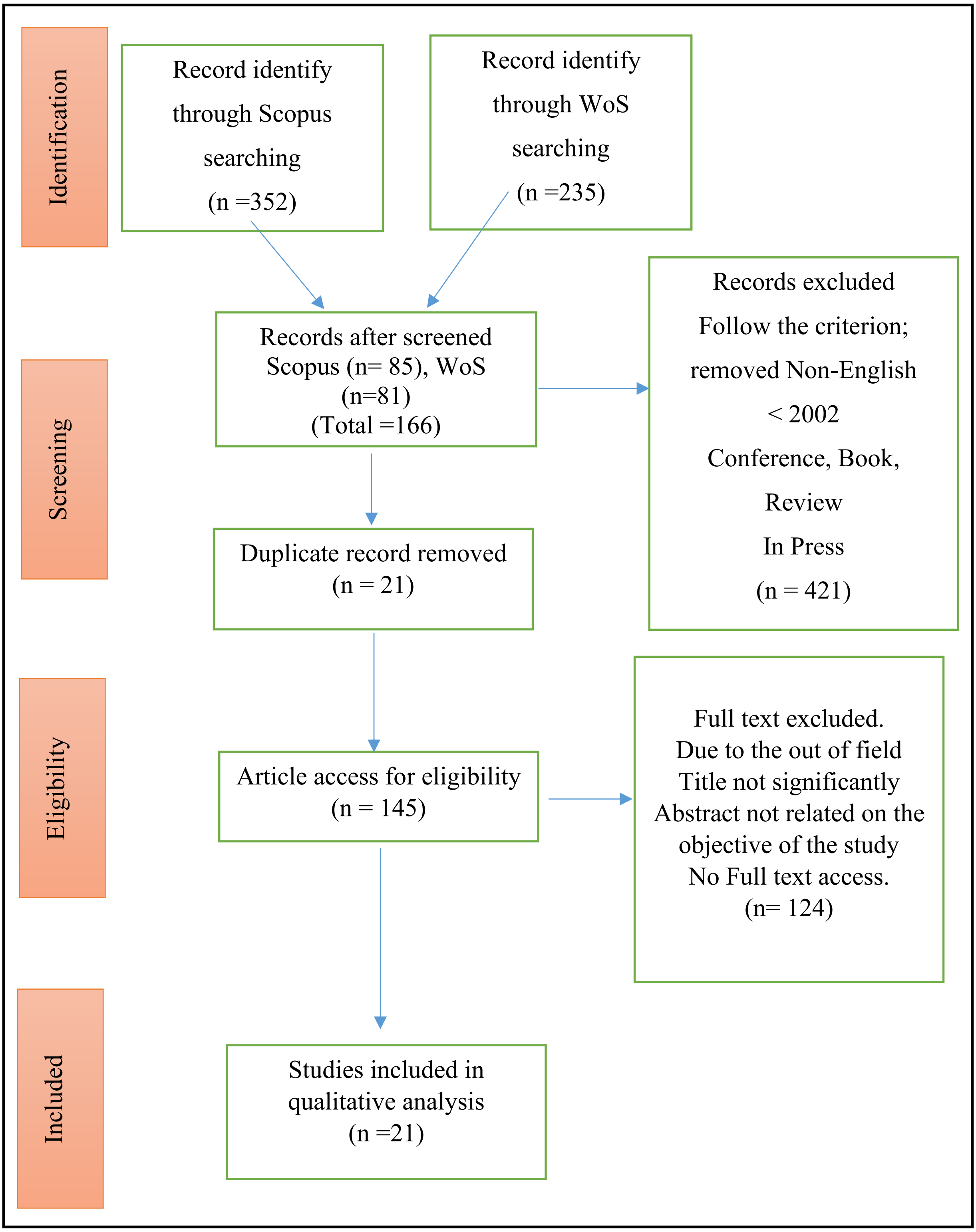

Figure 2. Flow Diagram Of The Proposed Searching Study (Page Et Al., 2021)

International Journal of Education, Psychology and Counseling
EISSN : 0128-164X
IJEPC
Volume 10 Issue 59 (September 2025) PP. 1216-1230
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Results and Discussion

Theme 1: Technology-Enhanced Mathematics Learning

Within the domain of technology-enhanced mathematics learning, numerous studies have demonstrated how diverse digital tools contribute to improved mathematical understanding and engagement. A notable focus has been placed on multimedia and computer-assisted instruction to accommodate learners' diverse needs and styles. Zin (2009) developed adaptive multimedia courseware tailored to individual learning preferences, revealing that aligning instruction with specific styles significantly improves student performance. Similarly, Maćkowski et al. (2022) introduced a multimedia method designed to support visually impaired learners, reporting measurable improvements in motivation and access to mathematical content. Mohamed Abdul-Rahmana (2020) extended this perspective by comparing program and learner-controlled strategies in mathematical instruction for slow learners. Both approaches resulted in enhanced mathematical thinking, highlighting that the customization of digital resources, whether visual, auditory, or interactive, can meaningfully support varied learning populations and enhance outcomes.

Another substantial body of literature addresses the integration of intelligent and adaptive technologies in mathematics education to support problem-solving skills and conceptual understanding. Liu et al. (2025) introduced the ChatGPT-MPS system, a generative AI-enhanced learning platform that provided real-time assistance and feedback in solving mathematics word problems. Their findings showed that students who used the system demonstrated higher post-test scores and reported increased interest and engagement. Similarly, Lin (2002) investigated the role of different computer graphic types such as animations, static images, and videos, and found that these media types significantly influenced student learning outcomes and attitudes, particularly when matched with learners' epistemological beliefs. Liu et al. (2025), Lin (2002) and Zin (2009) collectively reinforce the argument that intelligent and responsive educational systems, when effectively aligned with learner characteristics, can provide meaningful scaffolds for enhancing mathematical thinking and problem-solving competencies.

The role of augmented and visualized environments in deepening conceptual mathematical understanding has also received growing attention. Kounlaxay et al. (2021) explored the use of GeoGebra-based augmented reality (AR) tools that allow students to visualize and interact with 3D geometric figures. The implementation revealed improvements in comprehension and engagement, especially among students with difficulties grasping abstract geometric concepts. Al-Mashaqbeh (2016) further emphasized the impact of mobile technologies such as iPads in elementary settings, showing that students using these tools outperformed those receiving traditional instruction. Shi et al. (2024) similarly, leveraged visualization tools like GeoGebra and mathematical modelling, in the context of cooling curve experiments in chemistry, demonstrate that integrating real-life physical phenomena with computer-based mathematical modelling significantly deepened students' understanding. These studies underscore the value of visualization and interactivity in enhancing students' abstract reasoning and enabling them to build concrete understandings of mathematical relationships.

Furthermore, inclusive and adaptive digital learning designs play a central role in bridging educational gaps for underrepresented or disadvantaged student groups. Maćkowski et al. (2022) emphasized the importance of making mathematics content more accessible to visually

Volume 10 Issue 59 (September 2025) PP. 1216-1230
DOI 10.35631/IJEPC.1059089
impaired students through alternative representations of mathematical structures. Their adaptive multimedia approach demonstrated success in increasing learner autonomy and reducing dependency on instructors. Likewise, Mohamed Abdul-Rahmana (2020) noted the necessity of equipping educators with tools and training to effectively deploy computer-assisted strategies tailored for slow learners. The findings by both authors, complemented by those of Al-Mashaqbeh (2016), highlight that adaptive technological tools, when thoughtfully designed, can equalize learning opportunities across diverse student populations.

In summary, the collective findings from these studies reinforce the growing significance of technology-enhanced learning in mathematics education. Technological tools such as AI-based tutoring systems, AR visualization platforms, adaptive multimedia courseware, and mobile learning applications have demonstrated tangible improvements in student performance, motivation, and comprehension. Across different learner populations and contexts, the integration of such tools provides promising pathways toward inclusive, personalized, and effective mathematics education.

Theme 2: Integration of Programming and Computational Thinking in Education

In contemporary educational settings, the integration of computer programming with foundational learning objectives in mathematics and cognitive development has gained significant traction. Recent studies emphasize the necessity of supporting learners through tailored systems and tools, particularly in early and foundational programming education. Lee et al. (2023) introduced the Precision Education-based Timely Intervention System (PETIS), which demonstrated significant effectiveness in improving both programming skills and affective-domain learning objectives among K-12 students. The system's capacity to provide timely support and customized feedback led to improved performance and engagement. In a related context, Strawhacker & Bers (2019) examined the cognitive domains activated through coding instruction in younger learners using ScratchJr. Their findings indicated that foundational programming concepts were successfully acquired, although varying levels of understanding existed across different age groups, suggesting developmental influences on programming comprehension. Govender (2007) in a broader pedagogical analysis, highlighted that while students often reported confidence in problem-solving, many experienced difficulties in completing actual programming tasks, attributed to instructional methods that emphasize syntax and tools rather than problem-solving strategies. Collectively, these studies underscore that scaffolding through feedback mechanisms, age-appropriate programming environments, and problem-oriented teaching significantly enhances learners' computational thinking and cognitive engagement.

The growing emphasis on precision and adaptive instruction also aligns with the application of mathematical modelling within computational tasks. Lee et al. (2023) demonstrated that intelligent systems such as PETIS allow for timely adjustments in instruction, tailored to individual learning needs, thereby enhancing both technical skills and emotional engagement. Zhang et al. (2024) contributed to this narrative through their development of EmFace, a deep learning-based system that models facial features using explicit mathematical functions. While primarily used in image processing, the research exemplifies how complex computational and mathematical modelling can be successfully integrated, highlighting potential applications in advanced computer science education. Meanwhile, Govender (2007) reported that many learners struggle with abstract programming principles, often due to overly technical instruction lacking connection to broader problem-solving skills. When analyzed collectively,

Volume 10 Issue 59 (September 2025) PP. 1216-1230
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these studies suggest that mathematical modelling, combined with structured, learner-responsive instruction, presents a powerful framework for deepening programming comprehension.

Another dimension explored in the literature focuses on the developmental trajectory of learners acquiring programming knowledge. Strawhacker & Bers (2019) provided insights into how young children demonstrate varying levels of domain-specific reasoning when introduced to coding environments like ScratchJr. These findings imply that programming instruction must account for age-related cognitive capacities and learning styles. Govender (2007) added further perspective by analyzing learners' experiences across educational stages, revealing that student difficulty often lies not in exposure but in the design of instructional delivery. Echoing this, Lee et al. (2023) emphasized that pedagogical systems offering real-time, individualized support tend to yield stronger learning outcomes, particularly in affective and cognitive domains. Together, these perspectives advocate for an instructional paradigm that integrates age-sensitive, feedback-rich programming environments, thus promoting both cognitive growth and sustained interest in computational thinking.

Theme 3: Pedagogical Approaches and Learning Outcomes in STEM/Math Education

Research in recent years has revealed that the integration of structured pedagogical models and learning environments has notable implications for learning outcomes in STEM and mathematics education. Wei & Zhang (2024) analyzed how the Outcome-Based Education (OBE) model can be applied to mathematics education. Their findings highlight the positive influence of factors such as learning habits, learning ability, motivation, and the educational environment on students' academic performance. Similarly, Hwang et al. (2021) demonstrated that adopting a social regulation-based online learning framework encourages more meaningful learner behaviours and enhances learning achievements in mathematics, especially when compared to conventional self-regulated methods. Zhou et al. (2022) provided additional insight by showing how problematic smartphone use adversely affects mathematical performance, with mathematics anxiety and reduced learning interest acting as mediating factors. These studies collectively underline the importance of targeted pedagogical interventions, emphasizing that motivation, emotional state, and structured interaction with peers and materials contribute significantly to academic success in STEM subjects.

The integration of creative instructional models has also shown potential in enhancing student engagement and performance in STEM education. Lou et al. (2013) explored the impact of the TRIZ creative learning method through a STEM-based project involving pneumatic propeller ships. Their results revealed improvements in creativity, efficiency, and overall learning attitudes. Similarly, Baytak (2012) studied pre-service teachers' perceptions of instructional material development in technologically enriched settings. Although the findings indicated a general lack of attention to media characteristics, they underscored the growing importance of exposing student-teachers to more complex material development processes in preparation for modern classrooms. Hwang et al. (2021) in their investigation into social regulation-based learning, they reaffirmed that technology-enhanced, collaborative frameworks can lead to deeper engagement with learning content. The evidence suggests that combining creativity-based models with collaborative technology use can produce beneficial outcomes across diverse educational contexts.

Volume 10 Issue 59 (September 2025) PP. 1216-1230
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Another area of concern involves the differential impact of online learning on student performance, particularly regarding gender and personality traits. Idrizi et al. (2023) found that while female students in STEM, especially in computer science, perform strongly in traditional classroom settings, their performance lags slightly behind male counterparts in online environments. However, traits such as conscientiousness emerged as predictors of success regardless of gender or learning modality. In parallel, Mehlenbacher et al. (2015) observed that students engaged in collaborative writing tasks online often struggle to adapt strategies developed for face-to-face interactions. Despite these challenges, online collaboration tools like Google Docs were shown to support complex, team-based composition projects when used effectively. Zhou et al. (2022) added that individual differences such as anxiety and interest, mediated by external factors like technology use, can further influence outcomes in online and blended settings. These findings collectively suggest that pedagogical approaches in digital environments must account for psychological and behavioural factors to ensure equitable and effective learning experiences.

Finally, examining the intersection between psychological factors and learning performance highlights the nuanced relationship between student behaviours and academic outcomes. Zhou et al. (2022) demonstrated that students with high levels of problematic smartphone use tend to exhibit lower mathematics achievement, mediated by increased anxiety and diminished interest in the subject. Wei & Zhang (2024) also pointed to the importance of intrinsic factors such as motivation and learning resistance in shaping educational effectiveness under the OBE framework. Hwang et al. (2021) offered supporting evidence that structured peer engagement can counteract disengagement and foster more proactive learning behaviours. Taken together, these studies underscore the importance of addressing emotional and cognitive variables when designing pedagogical strategies for STEM education.

Conclusion

In summary, this review confirms that mathematics is a fundamental component of computer science education, vital for cultivating critical thinking, logical reasoning, and problem-solving abilities that underpin applications in artificial intelligence, data science, and software engineering. Analysis of 21 primary studies demonstrates that integrating mathematics with programming, computational thinking, and technology-enhanced teaching methods such as adaptive learning tools, augmented reality, and flipped classrooms can significantly improve conceptual understanding and learner engagement. To maximise these benefits, curriculum design should not only align mathematical content with technical skills but also address motivational and affective factors, including mathematics anxiety and equitable resource access. Such an approach prepares graduates to be both technically proficient and adaptable, capable of thriving in an ever-evolving digital landscape.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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International Journal of Education, Psychology and Counseling
IJEPC
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