DOI: https://dx.doi.org/10.4314/gjpas.v30i4.16

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 30, 2024: 585-595
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# ENHANCING STUDENT LEARNING THROUGH COMPUTATIONAL TECHNIQUES: A REVIEW OF EDUCATIONAL TECHNOLOGIES IN COMPUTER SCIENCE

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**(Received 20 September 2024; Revision Accepted 30 October 2024)**

## ABSTRACT

This paper presents a systematic literature review on the integration of computational techniques and educational technologies in computer science education. The study explores three main research questions: (1) Which computational techniques and educational technologies are most effective in enhancing student learning outcomes in computer science? (2) How do these technologies influence key aspects of learning, such as cognitive development, problem-solving abilities, and student engagement? (3) What are the main challenges and limitations associated with the implementation of these technologies, and how can they be addressed? Through an analysis of recent studies, we identify the most effective technologies, including virtual reality (VR), artificial intelligence (AI), learning analytics, and gamification. These tools significantly improve cognitive development, foster problem-solving skills, and boost student engagement. However, the findings also highlight several challenges, such as infrastructure limitations, lack of teacher training, and issues related to student accessibility and equity. To address these challenges, we propose recommendations focusing on infrastructure development, professional development for educators, and strategies to promote equitable access and integration. The paper concludes that while educational technologies offer significant potential to transform computer science education, addressing implementation barriers is critical to realizing their full impact.

**KEYWORDS:** Educational technologies, computational techniques, computer science education, virtual reality, artificial intelligence.

## INTRODUCTION

The integration of computational techniques and educational technologies in computer science education has the potential to significantly enhance student learning experiences(Haleem et al., 2022; Timotheou et al., 2023). As the demand for digital literacy and computational thinking skills continues to grow, educators are increasingly turning to innovative teaching tools and methodologies to better prepare students for future challenges. Technologies such as intelligent tutoring systems, gamified learning environments, and interactive simulations are being adopted to create more engaging and effective learning environments (Ramadhan et al., 2024) .

Despite the widespread adoption of these tools, there is still a need for a comprehensive understanding of their impact on various aspects of student learning, including knowledge acquisition, problem-solving skills, and overall engagement. The purpose of this literature review is to synthesize existing research on the effectiveness of educational technologies and computational techniques in computer science education. This review will explore how these technologies are being used to enhance the learning experience and improve student outcomes. By examining various studies, this review aims to identify which tools and methods are most effective, under what conditions they work best, and what challenges are associated with their implementation.

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Understanding these factors is crucial for educators, policymakers, and technology developers who are seeking to make informed decisions about integrating technology into computer science curricula.

To guide this investigation, the following key research questions have been formulated:

**1. Which computational techniques and educational technologies are most effective in enhancing student learning outcomes in computer science?**

**2. How do these technologies influence key aspects of learning, such as cognitive development, problem-solving abilities, and student engagement?**

**3. What are the main challenges and limitations associated with the implementation of these technologies in educational settings, and how can they be addressed?**

These research questions will help focus the literature review on identifying effective educational practices and technologies that can be used to support learning in computer science. By addressing these questions, this review aims to provide a clear picture of the current state of educational technology use in computer science, highlighting both successes and areas where further research and development are needed.

**METHODOLOGY**

This systematic literature review (SLR) was conducted to explore and analyze the use of computational techniques and educational technologies in computer science education. To ensure comprehensive coverage of the relevant academic literature, Scopus was selected as the sole database for this review. Scopus is a widely recognized and extensive database, providing access to peer-reviewed journals, conference papers, and book chapters across multiple disciplines, making it ideal for a focused review on the topic of interest (Pranckutė, 2021).

The search query used was ("Educational Technologies" OR "EdTech" OR "learning tools " OR "teaching tools" OR "digital learning" OR "online learning platforms" OR "e-learning" OR "virtual learning environments" OR "instructional technology") AND ("Computational Techniques" OR "programming" OR "algorithms" OR "machine learning" OR "simulations" OR "computational thinking" OR "flipped classroom" OR "gamification" OR "learning analytics" OR "intelligent tutoring systems") AND ("Student Learning" OR "student outcomes" OR "learning effectiveness" OR "student engagement" OR "learning strategies") AND ("Computer Science Education" OR "CS education" OR "computer science curriculum" OR "CS teaching" OR "STEM education") that yielded an initial set of 1,514 documents. These documents spanned multiple areas, so to refine the search and focus on recent developments in the field, the publication year was limited to a range between 2020 and 2024. This filter reduced the number of documents to 916. To further narrow the scope, the search was refined by limiting the subject area to computer science, which brought the number of documents down to 665. As the review was focused on primary research, the document type was limited to articles only, which reduced the number of documents to 267. To ensure that only finalized research was considered, another filter was applied to limit the search to documents at the final publication stage, leaving 250 documents. Lastly, the source type was restricted to journal publications, and the language was limited to English, which resulted in a final set of 110 documents.

To focus more precisely on studies relevant to educational technologies, specific keywords were applied during the search process, including “E-learning,” “Learning systems,” “Computer-Aided Instruction,” “Educational Technology,” “Online Systems,” “Intelligent Tutoring Systems,” and “Tutoring Systems.” These keywords ensured that the selected studies were directly related to the integration of educational technologies in computer science education. The resulting 110 documents were exported into an Excel sheet for further screening and analysis.

After exporting the 110 documents from Scopus into an Excel sheet, the next step involved was conducting a thorough duplicate removal process. This step ensured that any repeated articles from the initial search were identified and excluded from further analysis. Following the duplicate removal, the abstracts of the remaining documents were carefully read and evaluated to assess their relevance to the research questions of this review. This abstract screening process allowed for the exclusion of studies that did not directly address the integration of educational technologies or computational techniques in computer science education. As a result, the screening process led to a refined and final set of 79 documents, which were selected for full-text review and detailed analysis. Figure 1 illustrates the systematic procedure followed in the identification, screening and selection of articles.

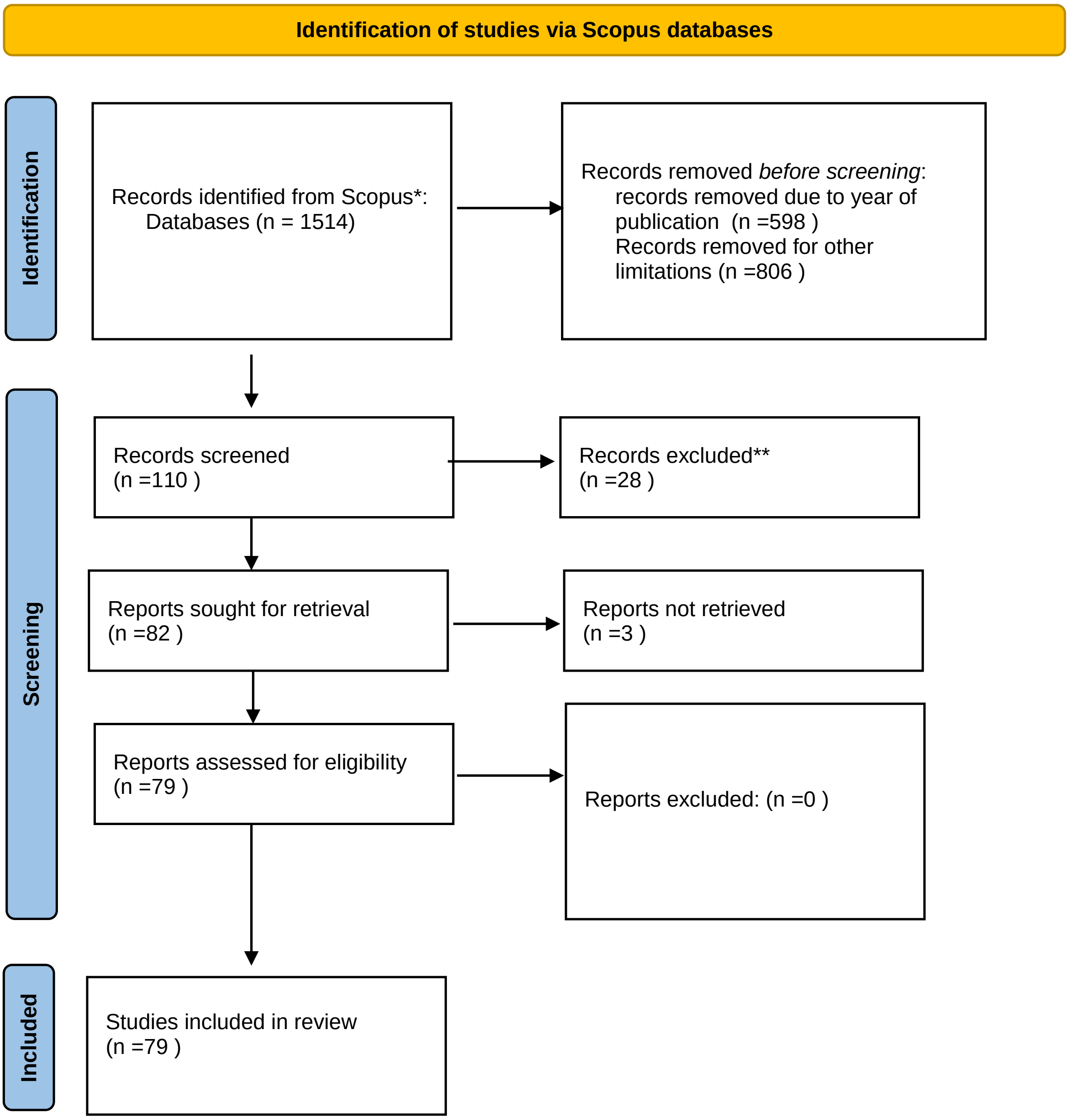


Figure 1: Article Identification Process

**Results and Analysis**

The results and discussion of this systematic literature review provide an in-depth analysis of the 79 selected studies, focusing on three key areas: the effectiveness of computational techniques and educational technologies in enhancing student learning outcomes, their influence on cognitive development, problem-solving, and engagement, and the challenges faced during their implementation. Each section synthesizes the findings from multiple studies, highlighting emerging trends, critical insights, and unresolved issues in the field of computer science education.

**Publication Trend of Article on Educational Technologies**

The bar graph displays the publication trend of articles on Educational Technologies from 2020 to 2024. The number of publications shows a general upward trend from 2020 to 2023, followed by a slight decline in 2024. In 2020, the total number of publications was the lowest, below 10. There is a noticeable increase in 2021 and 2022, where the numbers rise steadily. The peak occurs in 2023, with over 30 publications. However, 2024 shows a minor drop, though it still maintains a high total compared to earlier years, indicating sustained interest in the topic. This trend presented in Figure 2, suggests that the field of Educational Technologies has gained considerable traction in recent years, with 2023 being the most prolific year for publications.

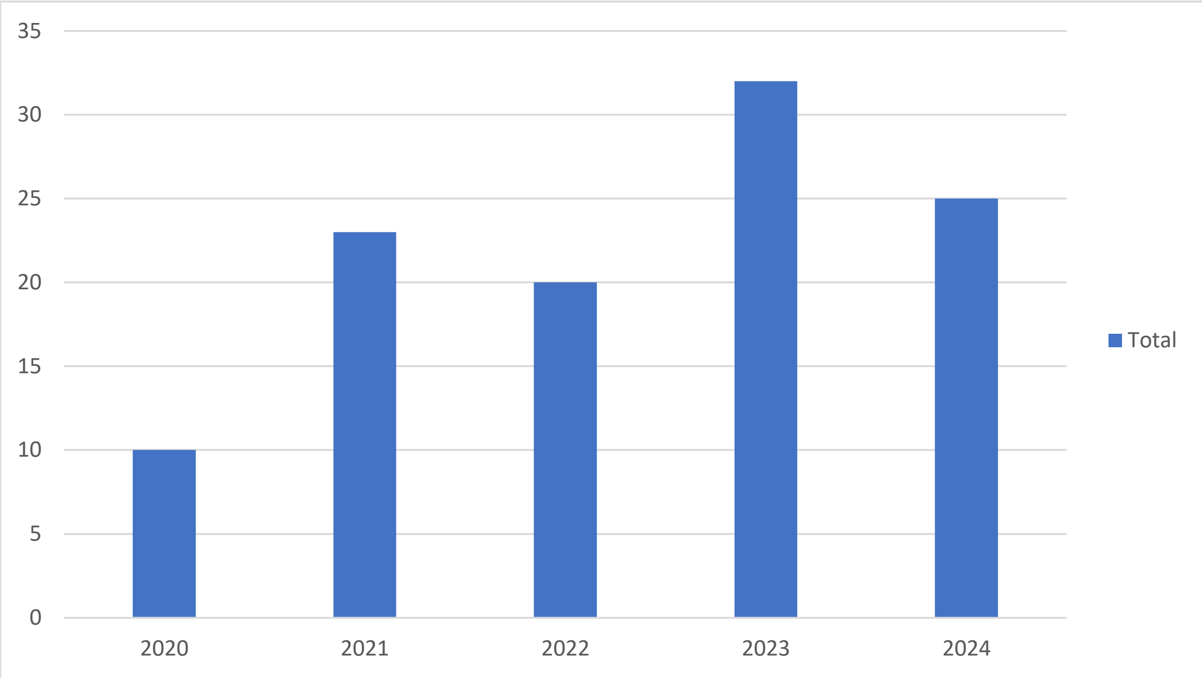


Figure 2: Articles Distribution per year

**Effectiveness of Computational Techniques and Educational Technologies in Enhancing Student Learning Outcomes**

The selected articles highlight various computational techniques and educational technologies that have been employed in computer science education to improve student learning outcomes. The analysis of these studies reveals significant insights into the effectiveness of these methods and tools.

(Mallek et al., 2024) conducted a comprehensive review to explore the synergy between educational technologies and pedagogical methods in computer science education. Their study emphasized the effectiveness of a blended learning approach, combining traditional teaching with digital resources such as learning management systems and interactive simulations. The authors reported that this combination improved students' comprehension and retention of complex computer science concepts, particularly in algorithmic thinking and programming.

(Marougkas et al., 2023) examined the impact of immersive virtual reality (VR) on teaching computer science concepts. Their findings indicated that VR environments could significantly enhance student engagement and understanding, particularly for abstract and complex topics such as data structures and algorithms. The study demonstrated that personalized VR experiences tailored to individual learning paces were particularly effective in supporting students who struggled with traditional teaching methods.

(Al Ahmad & Obeidallah, 2022) investigated a methodology designed to enhance problem-solving skills through computational thinking exercises. Their approach, which integrated game-based learning and problem-based learning activities, proved to be effective in fostering a deeper understanding of computational concepts. Students exposed to this methodology showed improved performance in coding tasks and were better able to apply theoretical concepts in practical scenarios.

Similarly, (Malik et al., 2021) proposed a model aimed at enhancing algorithmic thinking using educational technologies. Their model incorporated interactive coding environments and automated feedback systems, which allowed students to experiment with different solutions and receive immediate feedback. The study found that this approach not only improved students' problem-solving skills but also increased their confidence in tackling complex programming challenges.

(Ros et al., 2020) analyzed the self-perception of students' success in programming courses when educational technologies were used. Their study compared traditional lecture-based instruction with technology-enhanced learning environments, including online quizzes, interactive tutorials, and peer assessment tools. The results indicated a significant improvement in students' self-assessed understanding and their overall performance in programming assignments.

The study also highlighted that students were more motivated and engaged when they had access to these supportive technologies.

Overall, the analysis of these studies suggests that computational techniques and educational technologies can effectively enhance student learning outcomes in computer science. Tools such as immersive VR, interactive coding platforms, and automated feedback systems help bridge the gap between theoretical knowledge and practical application, making complex topics more accessible and engaging for students.

**Influence of Educational Technologies on Cognitive Development, Problem-Solving Abilities, and Student Engagement**

Several studies have highlighted the positive impact of educational technologies on cognitive development. For instance, (Lee et al., 2024) explored the use of virtual reality (VR) in training environments and its implications for cognitive load management. Their findings indicate that VR can reduce cognitive overload by providing immersive, interactive simulations that help students visualize and comprehend complex computer science concepts more effectively. This approach enables students to develop a more profound and intuitive understanding of topics like data structures and algorithms.

(Thipphayasaeng et al., 2024) introduced a digital twins-based cognitive apprenticeship model to enhance computational thinking. This model integrates real-time simulations with traditional problem-solving exercises, allowing students to iteratively refine their solutions based on immediate feedback. The study reported significant improvements in students' cognitive abilities, particularly in their capacity to decompose complex problems into manageable components and to think algorithmically.

The development of problem-solving skills is a critical aspect of computer science education, and several studies have focused on how educational technologies can support this process. (Skalka & Drlík, 2023)investigated the use of automatic source code evaluation tools in programming courses. These tools provide real-time feedback on students' code, allowing them to identify and correct errors independently. The study found that students using these tools demonstrated enhanced problem-solving abilities, as they were better able to debug their code and optimize their solutions.

(Tsai et al., 2024) explored the integration of meta-cognitive learning strategies into online learning platforms to foster problem-solving abilities. Their approach involved the use of reflective activities and self-assessment quizzes that encouraged students to think critically about their learning processes. The results showed that students who engaged with these strategies were more adept at applying theoretical knowledge to practical problems, suggesting that meta-cognitive strategies, when combined with digital tools, can significantly boost problem-solving skills.

Student engagement is a vital factor in educational success, and several articles addressed how educational technologies can enhance this aspect. (Er et al., 2024) examined engagement profiles in game-based learning environments and found that gamification elements, such as rewards and challenges, significantly increased student motivation and participation. Their study highlighted that students who were more engaged in the gamified environment showed improved learning outcomes and higher levels of satisfaction with the course.

(Ramansyah et al., 2023) developed a gamified Massive Open Online Course (MOOC) for computer science students. Their findings indicated that the interactive and competitive elements of the gamified MOOC contributed to higher levels of engagement compared to traditional online courses. Students were more likely to complete the course and participate in discussions, indicating that gamification can play a crucial role in keeping students motivated and actively involved in the learning process.

In a similar vein, (Xin & Singh, 2021) designed a learning analytics dashboard based on gamified learning strategies to enhance student engagement. This dashboard provided real-time insights into students' progress and encouraged them to set personal learning goals. The study found that students using the dashboard were more likely to stay on track and complete their assignments on time, suggesting that real-time analytics and feedback can significantly improve student engagement.

**Challenges and Limitations of Implementing Educational Technologies**

The implementation of educational technologies faces several challenges, which can be broadly categorized into technical, pedagogical, and instructional constraints. On the technical side, a prominent challenge involves maintaining the security and integrity of online assessments, as noted by (Moukhliss et al., 2023). The development of continuous authentication systems aims to prevent cheating and identity fraud during exams, but the complexity of implementing such solutions, coupled with resource constraints, makes widespread adoption difficult. Similarly, (Huerta et al., 2022) discusses the challenges educators face in using Learning Management Systems (LMS) like Moodle. Many teachers, especially those with limited technical knowledge, struggle with tasks such as creating question banks or utilizing advanced plugins.

Although tools like the FastTest plugin have been developed to simplify these processes, the learning curve remains steep for many educators. Furthermore, (Criollo-C et al., 2024) points out the technical barriers associated with integrating Virtual Reality (VR) into education. While VR offers the potential to make abstract concepts more understandable through immersive experiences, the lack of infrastructure and clear strategies for its use hinders its broader application in classrooms.

Pedagogical challenges also present significant obstacles to the effective use of educational technologies. (Ramansyah et al., 2023) highlights issues with student engagement in Massive Open Online Courses (MOOCs), where low completion rates and high dropout levels are common. Although gamification has been introduced as a strategy to enhance motivation and engagement in MOOCs, its adoption is still limited, and the methods require further development to maximize their effectiveness. Additionally, (Demartini et al., 2024a) points out the hesitancy of primary and secondary schools to embrace learning analytics tools, despite their proven benefits in higher education. Schools are often skeptical of the impact these tools may have and lack the training needed to implement them effectively. In online education, (Villegas-Ch et al., 2024) identifies a significant pedagogical challenge: sustaining student participation over time. Engagement typically decreases as courses progress, leading to poorer retention and academic performance, indicating the need for innovative, long-term engagement strategies tailored specifically for online learning environments.

Instructional constraints further complicate the adoption of educational technologies. (Alshumaimeri & Alshememry, 2024) notes the skepticism educators hold toward using Artificial Intelligence (AI) in language learning. Despite AI's potential to improve teaching English as a foreign language, many teachers are unsure about its effectiveness and are reluctant to integrate it into their instruction. This skepticism is mirrored in the reluctance of schools to use data-driven learning analytics, as highlighted by (Demartini et al., 2024a). Even though such tools can help identify at-risk students and tailor educational interventions, many educators are resistant to adopting these technologies due to concerns about instructional flexibility and the need for additional professional development. (Villegas-Ch et al., 2024) also discusses the difficulty of managing diverse learning environments in online settings. Instructors must navigate varying levels of student engagement and academic performance, which complicates the creation of inclusive and effective instructional strategies. This complexity underscores the need for more adaptable teaching methods that can address the diverse needs of students in digital learning spaces.

3.5 Summary of Key Features and Potential Benefits of Various Educational Technologies for Computer Science Education.

The integration of educational technologies into computer science education has gained significant momentum in recent years, driven by advancements in artificial intelligence, data analytics, and e-learning platforms. These technologies aim to enhance the learning experience, improve teaching effectiveness, and provide personalized learning opportunities. This summary presented in Table 1, highlights key features and potential benefits of various educational technologies, with a focus on their application in computer science education. From knowledge tracing and machine learning analysis to AI-driven tools for personalized learning, these innovations offer promising solutions to traditional and online education challenges.

Each technology serves a unique purpose whether by tracking student knowledge progress, predicting academic performance, or improving teaching behavior analysis and together they form a comprehensive toolkit that educators can use to address the diverse needs of learners. The following is a summary of the key features and potential benefits of these technologies, based on the reviewed studies.

**Table 1:** Summary of Key Features and Potential Benefits of Various Educational Technologies for Computer Science Education.

| S/N | Author(s) | Educational Technology | Key Features | Potential Benefits |
|---|---|---|---|---|
| 1. | (Yunianto et al., 2024) | GeoGebra | 11 applets, 22 short questions, active learning through programming and debugging | Promotes constructionist learning, enhances skills and encourages peer feedback |
| 2. | (Huerta et al., 2022) | Video Games and VR | Desktop and Virtual Reality game | Effective in improving learning outcomes |
| 3. | (Roski et al., 2024) | I3Learn Platform (UDL) | UDL principles guide design, clusters learner behaviors (Video, text, self-assessment) | Supports individualized learning through AI; Allows tracking of student activity |
| 4. | (Moukhliss et al., 2023) | Continuous Authentication System | Real -time identity verification, Live video streams, session recording | Enhances exam security, reduces cheating |
| 5. | (Agrawal & Shukla, 2023) | Text-to-Text Transformer(T5) | AQG using fast T5 library, ONNX framework, WSD, domain adaptation | Automates question generation, reduces manual workload |
| 6. | (Llanos-Ruiz et al., 2024) | Robotics for Curricular sustainability | Cross-sectional study on robotics teaching primary, secondary and non-formal education | Develops personal autonomy, collaborative skills, and emotional management |
| 7. | (He et al., 2023) | Gamification in Computer Information Technology | Gamification vs traditional teaching methods based on multiple intelligence and constructivism theories. | Improves motivation, learning achievement and engagement. |
| 8. | (Martín-Núñez et al., 2023) | AI for Computational Thinking | AI enhances motivation and understanding of computational thinking | Shows a link between motivation and computational learning. |
| 9. | (Demartini et al., 2024b) | AI-based learning analytics dashboard | AI dashboard for identifying students at risk, fostering collaboration, improving writing skills | Helps facilitator in facilitating and decision making processes to student needs |
| 10. | (Rodríguez-Jiménez et al., n.d.) | Simulation based training | Simulations for mathematics and scientific learning | Active learning, flexibility in online/blended environment |
| 11. | (Ariza, 2023) | Active Learning with PhyC | In home Labs, online learning with low cost hardware | Improved motivation, academic performance, and reduced gender disparity in STEM |
| 12. | (Costaş et al., n.d.) | Heroine's Learning Journey (HLJ) | Narrative driven STEM learning for women | Increased female participation and engagement in STEM courses |
| 13. | (Hu-Au, 2024) | Virtual Reality (VR) | VR molecular world interventions for chemistry education | Enhanced learning of abstract concepts, improved visualization skills |
| 14. | (Gencoglu et al., 2023) | Machine Learning for Teaching Behavior | Machine learning to analyze large-scale open-ended student responses, Latent Dirichlet Allocation (LDA) topic modeling | Enhances understanding of teaching behaviors, improves student feedback systems, supports student-centered learning environments. |
| 15. | (Shen et al., 2024) | Knowledge Tracing (KT) | Monitoring students' evolving knowledge states, EduData and EduKTM for data processing and KT model implementation | Facilitates personalized learning through continuous knowledge state monitoring; contributes to the progress of KT research. |
| 16. | (Flegr et al., 2023) | Inquiry Learning with Virtual and Real Experiments | Combines real and virtual experiments for inquiry-based learning in science | Increases conceptual understanding through complementary learning formats; equally effective in different experiment sequences. |

## CONCLUSION AND RECOMMENDATIONS

This study aimed to analyze the integration of educational technologies in computer science education and their impact on student learning outcomes, cognitive development, and problem-solving abilities. Technologies such as virtual reality (VR), artificial intelligence (AI), learning analytics, and gamification have proven to be particularly effective in enhancing these aspects of learning. These tools foster active engagement, provide personalized feedback, and help students navigate complex computer science concepts with greater ease. However, the implementation of such technologies is not without challenges, including high costs, infrastructure limitations, lack of teacher training, and issues related to accessibility and equity.

To address these challenges, educational institutions should prioritize the adoption of technologies demonstrated to be effective, such as VR and AI-based platforms, while investing in the necessary infrastructure to support their use. Equally important is the need for professional development and training for educators, enabling them to effectively integrate these tools into their teaching practices. Ensuring that these technologies align with key learning objectives such as cognitive development, problem solving skills, and student engagement will further enhance their impact. Additionally, strategies to mitigate implementation barriers, such as seeking alternative funding sources and fostering collaboration among stakeholders, are crucial for the successful integration of educational technologies in computer science education.

Looking forward, several potential areas for future research have emerged. First, studies should explore the long-term impact of educational technologies on student learning trajectories and career outcomes in computer science. Additionally, further investigation is needed into how to design equitable and accessible technologies for students from diverse socioeconomic backgrounds, ensuring that no student is left behind. Research could also focus on developing robust teacher-technology integration models that maximize the potential of these tools in the classroom. Ethical concerns, such as data privacy and algorithmic bias in AI-driven systems, must be addressed to ensure the responsible use of educational technologies. Finally, continued advancements in adaptive learning algorithms and the role of technology in fostering collaborative learning environments warrant further exploration.

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