Problem-Based Learning Models in Computer Science Education Supported by Digital Platforms

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ABSTRACT

Computer science education requires strong problem-solving skills, algorithmic thinking, and collaboration. Problem-Based Learning (PBL) is widely regarded as a relevant pedagogical approach to address these demands, particularly when supported by digital platforms that enable collaborative, exploratory, and contextual learning. This study aims to synthesize PBL models in computer science education supported by digital platforms, identify the roles of digital platforms in facilitating PBL, and evaluate its impacts and implementation challenges. A Systematic Literature Review with a qualitative synthesis approach was conducted on peer-reviewed journal articles and conference proceedings published between 2014 and 2024. A total of 36 studies were included and analyzed through thematic analysis and narrative synthesis. The findings indicate that digital PBL is implemented through several dominant patterns, including full PBL, hybrid PBL, and project-based PBL, with a strong emphasis on authentic problems reflecting real-world computing practices. Digital platforms function as pedagogical mediators that support collaboration, solution exploration, and reflective learning. Although digital PBL demonstrates positive effects on problem-solving skills, motivation, and collaboration, its effectiveness is highly dependent on pedagogical alignment, instructor readiness, and students' digital literacy.

Keywords: *computer science education; digital platforms; problem-based learning; systematic literature review; technology-enhanced learning.*

INTRODUCTION

Computer science education is a field of study that requires mastery of problem-solving skills, algorithmic thinking, and collaborative abilities in the context of modeling and solving complex computational problems. These characteristics indicate that computer science learning should not be oriented solely toward mastering syntax or technical procedures, but must encourage learners to develop analytical and reflective abilities when dealing with authentic problems. Rehman (2023) emphasizes that the main challenge in computer science education lies in the gap between conceptual understanding and the application of problem-solving skills in real-world contexts.

Within this context, Problem-Based Learning is regarded as a relevant pedagogical model because it places authentic problems at the center of the learning process and encourages learners to actively construct knowledge

through exploration and collaboration. PBL enables learners to develop higher-order thinking skills through problem analysis, solution design, and reflective evaluation of outcomes. Trullàs et al. (2022) demonstrate that problem-based approaches consistently support the development of critical thinking and problem-solving abilities when implemented within a clear pedagogical framework.

The development of digital platforms over the past decade has further expanded opportunities for implementing Problem-Based Learning in computer science education. Learning Management Systems, online programming platforms, computer-based simulations, and digital collaborative environments enable problem-based learning to be conducted in both synchronous and asynchronous modes, while supporting iterative exploration of computational solutions. Boltsi et al. (2024) emphasize that digital technology within the framework of Education 4.0 has the potential to strengthen problem-based learning when used to facilitate meaningful interaction, collaboration, and problem solving.

Nevertheless, the implementation of digital platform-based PBL in computer science education continues to present various academic challenges. Variations in PBL design across studies, ranging from full PBL to partial integration with other approaches, lead to inconsistencies in practice and learning outcomes. Asfani and Chen (2024) note that inconsistencies in pedagogical design within computer-supported collaborative learning-based PBL hinder efforts to synthesize findings and generalize the effectiveness of the model.

Another issue arises from the tendency to use digital platforms instrumentally without systematic pedagogical integration. In several studies, technology is positioned more as a technical support tool than as a mediator of the problem-based learning process. This condition results in digital platforms failing to fully support key PBL stages such as problem analysis, self-directed learning, and reflection. Opre et al. (2022) show that learning technologies only have a positive impact on active learning when they are designed in alignment with pedagogical goals and strategies.

A review of the literature indicates that studies on PBL and digital platforms in computer science education remain fragmented. Some studies focus on the effectiveness of PBL without examining in depth the role of digital technology, while others emphasize the use of digital platforms without positioning them as an integral part of the PBL framework. Sentriyo et al. (2023) assert that the integration of digital technology in PBL is often additive rather than transformational, resulting in suboptimal pedagogical benefits.

Several previous studies have made important contributions but still exhibit clear limitations. Asfani and Chen (2024), through their study entitled Problem or Project-Based Computer-Supported Collaborative Learning Practices in Computer Education: A Systematic Review of SSCI Articles Published from 2014 to 2023, map PBL and project-based learning practices supported by digital

collaboration, but do not specifically classify PBL models in computer science education based on types of digital platforms. Rehman (2023), in Trends and Challenges of Project-Based Learning in Computer Science and Engineering Education, highlights challenges of PBL in computer education, but focuses more on project-based learning rather than PBL as a pedagogical model. Meanwhile, Boltsi et al. (2024) examine learning technologies and methodologies within the Education 4.0 framework, but do not position PBL as the primary focus of pedagogical analysis.

Based on these three studies, an explicit research gap can be identified. Asfani and Chen (2024) do not consolidate PBL models based on specific digital platform support in computer science education, Rehman (2023) addresses trends and challenges of project-based learning without a systematic synthesis of digital PBL, while Boltsi et al. (2024) discuss educational technology in general without mapping the implementation of PBL as a pedagogical framework. Thus, there is no systematic literature review that comprehensively synthesizes Problem-Based Learning models in computer science education supported by digital platforms, while simultaneously examining implementation patterns, platform types, and their impacts and limitations based on cross-study empirical evidence.

Based on this gap, this study aims to synthesize models of Problem-Based Learning in digital platform-based computer science education, identify the roles of digital platforms in supporting PBL implementation, and evaluate empirical findings related to the effectiveness and challenges of its application. Theoretically, this study contributes to the conceptual mapping of digital PBL in computer science education, while practically providing a foundation for the development of more structured and evidence-based digital PBL learning designs (Sauer and Seuring, 2023).
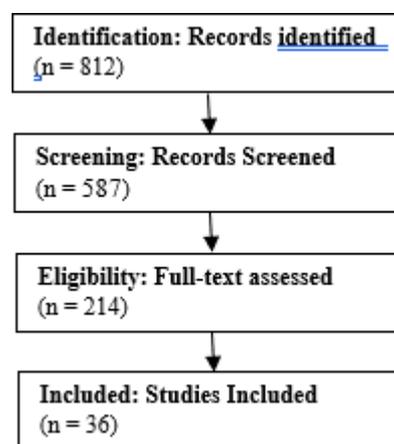
METHOD

This study employs a Systematic Literature Review (SLR) design to systematically synthesize empirical findings on models of Problem-Based Learning in computer science education supported by digital platforms. The SLR approach is selected because it enables the mapping of research patterns, evaluation of evidence quality, and transparent and structured integration of findings across studies, making it appropriate for addressing gaps in the literature related to the fragmentation of PBL and technology studies in computer science education (Sauer and Seuring, 2023).

The literature search was conducted across five reputable scientific databases, namely Scopus, Web of Science, IEEE Xplore, ERIC, and Google Scholar, covering publications from 2014 to 2024. The search strategy employed combinations of the keywords "Problem-Based Learning", "Computer Science Education", and either "Digital Platform" or "Online Learning". The inclusion criteria comprised reputable journal articles and conference proceedings reporting empirical research on the implementation of PBL in computer science education with digital platform support. Non-empirical studies, duplicate

publications, and manuscripts without full-text availability were excluded to maintain the relevance and quality of the analysis (Asfani and Chen, 2024).

The study selection process followed the PRISMA flow systematically, beginning with identification and proceeding to final inclusion. Of the 812 articles identified in the initial stage, 587 articles remained after duplicate removal and were screened based on titles and abstracts. The full-text eligibility assessment resulted in 214 articles, and following methodological quality evaluation, 36 studies were included in the final synthesis. Data from the selected studies were extracted and analyzed using cross-study thematic analysis and subsequently integrated through narrative synthesis to identify implementation patterns, the roles of digital platforms, as well as the impacts and challenges of digital PBL (Sentriyo et al., 2023).

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RESULT AND DISCUSSION

Patterns and Characteristics of Problem-Based Learning Models in Computer Science Education

The synthesis of the reviewed studies indicates that Problem-Based Learning in digital platform-based computer science education is implemented through several main model patterns, namely full PBL, hybrid PBL, and project-based PBL. Full PBL positions authentic problems as the core of the entire learning process, from initial exploration to solution evaluation, whereas hybrid PBL combines problem-based approaches with direct instruction or project-based learning to accommodate curricular demands and learner readiness. Asfani and Chen (2024) emphasize that these model variations reflect educators' adaptations to the complexity of computer science content and the constraints of digital learning contexts, while simultaneously resulting in significant differences in pedagogical design across studies.

A key characteristic of digital PBL in computer science education lies in the use of authentic problems that represent real computational practices, such as programming, systems analysis, or algorithmic problem solving. These problems are designed to encourage learners to integrate conceptual knowledge with practical skills through exploration and collaboration supported by digital

platforms. Rehman (2023) demonstrates that PBL focusing on real-world computational contexts is more effective in developing problem-solving skills than approaches that emphasize procedural exercises alone, particularly when problems are presented in open-ended and cognitively challenging forms.

Within digital learning environments, the role of educators in PBL shifts from information transmitters to facilitators who guide the learning process and provide appropriate scaffolding. Educators are responsible for designing problems, guiding online discussions, and facilitating reflection and solution evaluation through digital platforms, both in synchronous and asynchronous interactions. Opre et al. (2022) emphasize that the effectiveness of digital PBL is highly dependent on educators' ability to manage learning interactions and utilize technology as a pedagogical mediator rather than merely as a technical support tool.

Digital Platform Support in the Implementation of Problem-Based Learning

Digital platforms play a crucial role in enabling the effective implementation of Problem-Based Learning in computer science education, particularly in facilitating collaboration, solution exploration, and the management of problem-based learning processes. The synthesis of the literature shows that digital platforms function not only as content delivery media, but also as learning environments that mediate learners' cognitive and social interactions during problem-solving activities. Boltsi et al. (2024) assert that within the context of Education 4.0, digital technology contributes pedagogically when it is designed to support higher-order thinking activities and collaborative learning.

Learning Management Systems are the most commonly used type of digital platform to support PBL in computer science education. LMS provide a learning structure that enables group management, online discussions, distribution of learning resources, and systematic documentation of problem-solving processes. In the context of PBL, LMS function as coordination spaces that integrate various problem-based learning activities. Hendarwati et al. (2021) show that the integration of online learning with collaborative PBL enhances learner engagement and the quality of interactions when LMS are used consistently in accordance with PBL pedagogical stages.

In addition to LMS, online programming platforms play a central role in supporting the exploration and testing of computational solutions in PBL. These platforms enable learners to write, execute, and iteratively revise code, as well as to share their work within collaborative environments. The use of online programming platforms strengthens the connection between authentic problems and the application of computational concepts. Lah et al. (2024) demonstrate that e-modules and problem-solving-based platforms in computing education are effective in supporting self-directed learning and problem solving when they are directly linked to problem-based task contexts.

Simulation platforms and visualization tools are also widely utilized in PBL implementation, particularly for computer science topics that are abstract or complex in nature. Simulations allow learners to model systems, observe the

consequences of computational decisions, and test hypotheses within safe environments. This approach enriches the problem-solving process through exploratory experiences that are difficult to achieve through conventional instruction. Opre et al. (2022) emphasize that the use of computer-based tools that support active learning can enhance conceptual understanding when employed as part of a well-planned pedagogical strategy.

To summarize the role of digital platforms in supporting the implementation of Problem-Based Learning, the synthesis of research findings is presented in Table 1, which maps types of digital platforms, pedagogical functions, and their implications for the PBL process in computer science education.

Table 1. Roles of Digital Platforms in Supporting Problem-Based Learning in Computer Science Education

Digital Platform Type	Primary Pedagogical Function	Implications for PBL Implementation
Learning Management Systems	Coordination, discussion, and learning management	Supports structured collaboration and documentation of problem-solving processes
Online Programming Platforms	Code development, testing, and iteration	Enables direct application of computational concepts to authentic problems
Simulation Tools	Modeling and visualization of abstract systems	Enhances conceptual understanding through exploratory problem solving
Collaboration and Version Control Tools	Team-based project coordination	Promotes accountability and collaborative problem-solving skills
Multimedia and Interactive Tools	Problem contextualization and scaffolding	Supports problem framing and learner engagement

The analysis of Table 1 indicates that digital platforms in PBL function as pedagogical mediators that strengthen the problem-solving process, rather than as the primary determinants of learning success. The effectiveness of digital PBL is highly dependent on the alignment between platform functions and the pedagogical objectives pursued at each stage of PBL. Studies reporting positive impacts generally show that platforms are selectively chosen to support problem analysis, solution exploration, and learning reflection. Sentriyo et al. (2023) emphasize that the integration of digital technology in PBL provides pedagogical added value when the technology is designed to reinforce, rather than replace, problem-based learning processes.

Impacts and Challenges of Digital-Based PBL Implementation

The synthesis of the literature demonstrates that digital platform-based Problem-Based Learning has a significant positive impact on the development of learners' problem-solving skills and computational thinking abilities in computer science education. Digital PBL enables learners to actively engage in the analysis of authentic problems, exploration of computational solutions, and reflection on

learning processes and outcomes. Weng et al. (2022) show that problem-based learning integrated with digital activities is more effective in fostering higher-order thinking skills and learner creativity compared to conventional instructional approaches.

Beyond cognitive impacts, digital PBL also contributes to enhanced collaboration and learning motivation. Digital environments allow learners to work flexibly in teams, share ideas, and receive feedback through various online communication channels. These collaborative interactions strengthen learning engagement and collective responsibility in problem solving. Hendarwati et al. (2021) report that the integration of online learning with collaborative PBL models significantly increases learners' active participation and learning motivation.

Nevertheless, the implementation of digital PBL also faces several challenges that require critical attention. Technical challenges, such as limited infrastructure, unequal access to technology, and the complexity of platform use, may hinder the smooth implementation of learning processes. These conditions may create participation gaps and divert learners' focus from problem solving to mastering technical aspects. Aydınlar et al. (2024) indicate that differences in learners' levels of digital literacy are a key factor influencing the effectiveness of technology-based learning.

Another challenge identified in the literature relates to the cognitive load experienced by learners during digital PBL. The combination of complex computational problems and the demands of using digital platforms can result in cognitive overload, particularly for learners who are not yet accustomed to self-directed and collaborative learning. This condition may reduce learning effectiveness if not balanced with adequate pedagogical scaffolding. Hutchins and Biswas (2023) emphasize that pedagogical support and technology design that are sensitive to learners' needs are essential prerequisites for technology-supported problem-based learning.

In addition to learner-level challenges, the literature also highlights methodological limitations in previous studies examining digital PBL. Many studies employ short-term research designs, limited sample sizes, and diverse learning outcome indicators, making it difficult to compare and generalize findings. Videnovik et al. (2023) demonstrate that methodological inconsistencies in technology-based computer science education research contribute to variations in findings regarding the effectiveness of learning models.

Thus, this discussion confirms that digital platform-based PBL holds substantial potential for enhancing the quality of computer science education. However, its effectiveness is conditional and influenced by technological readiness, digital literacy, pedagogical support, and the quality of research design. These findings underscore the importance of more integrated and evidence-based approaches in designing, implementing, and evaluating digital PBL to optimize its positive impact in a sustainable manner (Zheng et al., 2023).

CONCLUSION

Based on the results of the systematic literature review, this study concludes that digital platform-based Problem-Based Learning has significant potential to enhance the quality of computer science education, particularly in the development of problem-solving skills, computational thinking, collaboration,

and learner engagement. The synthesis of the literature indicates that digital PBL is most effective when implemented through authentic problems that represent real computational contexts and are supported by digital platforms that facilitate meaningful solution exploration and collaborative interaction (Weng et al., 2022).

However, the effectiveness of digital PBL implementation is not universal and is highly dependent on coherent integration between pedagogical design and technological support. The findings suggest that digital platforms function as learning mediators rather than as the primary determinants of PBL success. Consequently, the instrumental use of technology without a clear pedagogical framework tends to result in limited learning outcomes. In addition, challenges such as disparities in digital literacy, cognitive load, and variations in the quality of instructional facilitation further influence the outcomes of digital PBL implementation in computer science education (Hutchins and Biswas, 2023).

Based on these findings, this study recommends that educational practitioners and curriculum developers design digital PBL with an emphasis on pedagogical design consistency, adequate scaffolding, and the selection of platforms aligned with the stages of problem-based learning. For future research, further empirical studies with more robust methodological designs, such as design-based research and longitudinal studies, are required to evaluate the sustainability of digital PBL impacts and to strengthen the evidence base for the development of technology-enhanced computer science education (Sauer and Seuring, 2023).

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