

Generative Artificial Intelligence and Problem-Based Learning: Reengineering Cognitive Activity in Digital Learning Environments

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Abstract

The rapid development of Generative Artificial Intelligence (GenAI) is transforming digital learning environments and raising new questions about the nature of learners' cognitive activity. This article examines how Problem-Based Learning (PBL) can be reimagined in the context of generative AI, with particular attention to the preservation of active learning, critical thinking, problem-solving, autonomy, and collaborative knowledge construction. Based on an analysis of recent literature and empirical studies, the article explores the pedagogical roles that GenAI can play throughout the different stages of PBL, as well as the boundaries between cognitive scaffolding and the substitution of learners' mental activity. The analysis highlights the potential of GenAI to support problem analysis, information exploration, idea generation, personalized feedback, hypothesis development, and the simulation of alternative solutions. At the same time, it identifies important challenges related to overreliance on AI, critical thinking, academic integrity, data protection, digital equity, human interaction, and the changing role of teachers. The article proposes a theoretical shift from "AI-supported problem-based learning" toward "generative AI-mediated problem-based learning," in which AI functions as a cognitive scaffold and mediator rather than a substitute for learners' thinking. Within this perspective, learners remain responsible for questioning, verifying, evaluating, justifying, and making decisions, while teachers assume a central role as facilitators, designers, guides, and supervisors of the learning process. The article concludes that the educational value of GenAI depends not primarily on the technology itself, but on the pedagogical design governing its integration into PBL.

Keywords: Generative Artificial Intelligence; Problem-Based Learning; Cognitive Scaffolding; Active Learning; Digital Learning Environments; Learner Autonomy; Collaborative Learning; Teacher Role.

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Introduction

Contemporary education is undergoing a rapid shift from educational models that focus on the transmission and reception of knowledge to models that make the learner an active participant in constructing, applying, and utilizing knowledge to address various real-world problems and situations. This shift has contributed to a growing interest in active learning strategies that make the learner's cognitive activity, interaction, reflection, and collaboration central elements of the educational process. In this context, Problem-Based Learning (PBL) has emerged as one of the pedagogical models that shifts the focus of the educational process from content delivery to engagement with a complex problem requiring research, analysis, identification of knowledge needs, generation of alternatives, collaboration, and reflection on the learning process. According to the framework presented by Hmelo-Silver (2004), students in PBL learn by addressing complex problems that typically do not have a single solution; they work in groups to identify what they need to learn, and then engage in self-directed learning, the application of knowledge, and reflection on the strategies used to solve the problem. Thus, the educational value of problem-based learning lies not only in arriving at the final answer but also in the cognitive and social processes the learner undergoes while constructing the solution. With the increasing shift toward digital learning environments, digital technologies are no longer merely tools for presenting content or providing access to knowledge sources; rather, they have become an integral part of the structure of the learning activity itself, offering possibilities for interaction, simulation, collaboration, and access to diverse sources of information. However, the most profound transformation has emerged with the rise of Generative Artificial Intelligence (GenAI), particularly since the widespread adoption of large language model applications such as ChatGPT beginning in late 2022. These technologies have become capable of interactively generating texts, explanations, ideas, and proposed solutions, which has transformed the nature of the relationship between the learner, information, and technology. Kasneci et al. (2023) have shown that large language models offer significant potential for content creation and for supporting interaction and personalized learning, but, as noted in , they also require learners and teachers to possess digital and cognitive competencies to understand the limitations of these systems, as well as the need to adopt educational strategies that emphasize critical thinking, information verification, and human supervision.

The significance of this shift goes beyond simply providing an additional source of information; it extends to rethinking the nature of the cognitive activity engaged in by the learner. If the essence of problem-based learning lies in the learner seeking the knowledge necessary to understand the problem, analyzing the data, proposing hypotheses, compare alternatives, and construct solutions, then the ability of generative AI to instantly propose explanations, solutions, and alternatives raises a fundamental pedagogical question about the learner's role within this process. Hence, the issue is no longer whether generative AI can help the learner solve the problem, but rather in determining how it can be utilized so that the learner remains engaged in the cognitive activity of knowledge production, rather than AI becoming a substitute for thinking, inquiry, and problem-solving.

Recent experimental studies have begun to provide important insights into the potential of integrating generative AI into problem-based learning. Lim et al. (2025) developed a generative AI-supported educational simulation based on PBL principles to train pre-service

teachers in problem-solving. The results showed a statistically significant improvement in problem-solving skills among students in both the rule-based simulation and the AI-enhanced simulation groups compared to the text-based scenario, and students reported that the AI-supported environment provided a greater sense of realism and immersion due to dynamic interactions with intelligent agents. This finding is particularly significant because it suggests that generative AI has the potential to evolve from a mere tool for presenting information to a component in the design of more dynamic and authentic problem-solving environments (Lim et al., 2025).

In another vein, Huang et al. (2025) presented a two-stage, generative AI-supported personalized problem-based learning model, aimed at addressing some of the limitations associated with traditional problem-based learning, particularly the difficulty of providing support and feedback tailored to individual differences among learners. The quasi-experimental study included 62 college students, and the results showed that the proposed model contributed to improved reading performance, motivation, and engagement compared to traditional problem-based learning. This finding reveals the potential to use generative artificial intelligence as a tool for scaffolding and personalized support within the stages of PBL, rather than merely as a source of answers (Huang et al., 2025).

However, the positive results of these studies should not lead to a deterministic technological view that sees generative artificial intelligence as an automatic solution to the problems of problem-based learning. A recent systematic review of 407 publications on generative AI in education revealed that the literature focuses largely on its applications and potential impacts, ethical considerations and risks, and user experiences, while gaps remain regarding empirical studies and the understanding of the conditions for the effective and responsible use of these technologies (Yusuf et al., 2024). Wang et al. (2024), in a systematic review of empirical studies, noted that the majority of the studies they reviewed reported positive effects of generative AI on certain learning outcomes, particularly when it provides personalized feedback; however, overreliance on it can raise concerns related to critical thinking and creativity.

The significance of this issue is amplified in the context of problem-based learning (PBL) due to its collaborative nature. PBL is not based solely on the dyadic relationship between the learner and the digital tool, but rather on a network of interactions among the learner, the problem, knowledge, peers, and the instructor. In this regard, a study by Otto et al. (2025), which examined the experiences of 83 students at a university that adopts a PBL-based model, revealed that the use of generative artificial intelligence has become part of both individual and group study practices, but at the same time has created tensions related to cognitive and practical interaction, the relationship between students and project groups, and the formal and informal rules governing the use of AI. These findings reveal that the integration of GenAI into PBL is not merely the addition of a technological tool to an existing educational model, but may lead to a reshaping of the relationships and practices underpinning the learning activity itself (Otto et al., 2025).

In the same vein, the study by Scholkmann et al. (2025) is of particular relevance to this article, as it sought to move beyond examining the practical uses of generative AI to developing a theoretical framework for the relationship between GenAI and PBL through a design experiment at Aalborg University. The emergence of this type of study reflects a shift in research from the question “How do students use AI?” to a deeper inquiry into how PBL is reshaped when generative AI () becomes part of the knowledge-building process. However, there

remains a need for more integrated theoretical frameworks that link the nature of cognitive activity, the scaffolding provided by AI, social interaction, critical thinking, and the teacher's role in organizing this interaction (Scholkmann et al., 2025).

Therefore, the real challenge lies not in technically integrating generative AI into problem-based learning, but in reengineering the relationship between the problem, the learner, the teacher, peers, and AI in a way that preserves the essence of active learning. Using AI to analyze the problem and generate the final solution may reduce the need for certain cognitive processes that the learner is supposed to engage in, whereas an approach that guides the learner to ask better questions, compare different answers, verify evidence, critique AI outputs, and interpret its decisions can make GenAI a cognitive scaffold that enhances—rather than replaces—mental activity.

From this perspective, it becomes necessary to move from the concept of “AI-supported problem-based learning” to a more profound conception: “generative AI-mediated problem-based learning” (Generative AI-Mediated Problem-Based Learning), in which AI is not merely an external tool but a mediator that can reshape the processes of inquiry, knowledge generation, and problem-solving, while the learner remains the primary agent in judgment, critique, and decision-making.

Research Problem

A review of recent literature reveals a fundamental paradox: on the one hand, empirical studies indicate that the use of generative AI in PBL-based environments can support problem-solving, personalization, motivation, and immersion, and enable more dynamic interactions (Huang et al., 2025; Lim et al., 2025). On the other hand, analytical and qualitative studies reveal risks and tensions related to reliance on AI outputs, critical thinking, group interaction, and rules governing usage (Otto et al., 2025; Tlili et al., 2023; Yusuf et al., 2024).

This paradox suggests that the question should not be reduced to the dichotomy of “is AI beneficial or harmful,” because the educational value of GenAI is not determined by the characteristics of the technology itself, but rather by how the learning activity in which it is integrated is designed. Therefore, the integration of generative artificial intelligence () into PBL requires a reexamination of the principles that determine: What should the learner do on their own? What can the technology support? When does the assistance provided by AI become a cognitive scaffold? When does it become a substitute for mental activity? How can we preserve the social interaction and negotiation that are at the heart of PBL? And what new role should the teacher play in organizing this interaction?

Thus, the theoretical problem from which this article proceeds is the gap between the rapid expansion of experimental applications of generative artificial intelligence within problem-based learning and the need for a pedagogical theoretical framework that defines the conditions for its integration in a way that preserves the essence of active learning, and ensures the learner's continued engagement in problem analysis, inquiry, critical thinking, solution construction, and reflection.

Accordingly, the article seeks to reimagine problem-based learning in digital learning environments by analyzing recent literature on PBL and generative AI, and to uncover the shifts that GenAI imposes on the roles of the learner, the teacher, the problem, and collaborative interaction, ultimately proposing a theoretical framework that positions generative AI as a scaffold and cognitive mediator rather than a substitute for the learner's mental activity.

Based on this, the main question of the article can be formulated as follows:

How can problem-based learning in digital learning environments be reimaged in light of the

potential of generative AI, ensuring its use as a cognitive mediator and scaffold that enhances active learning, critical thinking, problem-solving, and collaborative knowledge construction?

This study aims to identify: the transformations that generative artificial intelligence has brought about in the nature and practices of problem-based learning.

The pedagogical roles that GenAI can play in the stages of problem-based learning.

The boundaries between using AI as a cognitive scaffold and using it as a substitute for the learner's cognitive activity.

How to utilize GenAI in a way that fosters critical thinking, independence, and collaborative learning rather than cognitive dependence.

Redefining the teacher's role in facilitating interaction between the learner, the problem, peers, and artificial intelligence.

The design principles that should underpin a model of problem-based learning mediated by generative AI.

1. Definition of Artificial Intelligence:

Researchers Russell & Norvig (2020) define artificial intelligence as the ability of digital and computational systems to perform a range of tasks traditionally associated with the mental capabilities of intelligent beings, such as reasoning, thinking, understanding meaning, generalizing, and learning from past experiences and knowledge, thereby enabling the system to generate appropriate responses to the situations it encounters.

Artificial intelligence can also be viewed as an integrated system of technologies, software, and intelligent systems that operate through advanced computers and digital devices and seek to simulate a number of human cognitive and mental abilities, particularly analysis, reasoning, and decision-making. This system enables the efficient, accurate, and rapid execution of a wide range of tasks, which has made its adoption a growing strategic trend among institutions and companies aimed at improving performance, enhancing efficiency, and achieving organizational and institutional goals (A'yib, 2026, p. 331).

Thus, the two definitions complement each other in defining the nature of artificial intelligence; while the definition by Russell and Norvig (2020) focuses on the functional and cognitive aspects—namely, thinking, learning, reasoning, adaptation, and goal achievement—while Aib's (2026) definition focuses on the technical and applied aspects through which these capabilities are embodied in the form of systems, software, and digital tools. Consequently, artificial intelligence can be viewed as an intelligent technological system based on a set of algorithms and software capable of simulating certain cognitive processes, processing and learning from information, reasoning, and making decisions—allowing it to perform specific tasks and adapt to the requirements of different situations efficiently and effectively.

2. The Concept of Generative Artificial Intelligence:

Generative AI is considered one of the advanced subfields of artificial intelligence, and has witnessed rapid development and widespread adoption, particularly since 2022, coinciding with the emergence of models capable of producing new and diverse content, including text, images, music, videos, and more. This type of artificial intelligence is based on algorithms and machine learning models trained on massive amounts of data, enabling them to acquire patterns and cognitive

relationships that can later be utilized to generate new outputs (Alto, 2023).

Generative AI is thus not limited to analyzing, classifying, or processing available data; rather, it goes beyond that to produce new content based on the patterns the models have extracted during training. This generative capability is achieved through the use of advanced techniques in machine learning and deep learning—particularly artificial neural networks and deep learning models with complex architectures—along with natural language processing techniques that enable the models to understand linguistic inputs and generate coherent textual responses. Generative AI thus represents a paradigm shift in the applications of artificial intelligence, moving from a focus on prediction, classification, and data analysis to the ability to generate, create artificially, and produce new content that can be applied across various academic, professional, and educational fields. (Abdi, 2025)

3. The Role of the Teacher in Artificial Intelligence:

In the age of artificial intelligence, the role of the teacher is shifting from that of a mere transmitter of knowledge to that of a facilitator, mentor, and collaborative creator of knowledge, while the human dimension and educational responsibility remain at the heart of the educational process.

The key points put forward by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2025) regarding the redefinition of the teacher's role in the era of artificial intelligence include:

- **Maintaining the centrality of the teacher and the learner:** Interaction and collaboration between teachers and learners remain the essence of the educational process, despite the use of artificial intelligence.
- **Not Replacing Teachers:** AI tools should not be designed to replace the legitimate professional and educational responsibilities of teachers.
- **Protecting teachers' rights:** It is essential to establish legal frameworks and protections that guarantee teachers' rights when integrating AI into education.
- **Ensuring Access to Technology:** Long-term commitments and funding must be secured to ensure that teachers have equitable access to technological tools, environments, and artificial intelligence.
- **Redefining Teachers' Roles:** The transformative potential of AI necessitates a continuous reassessment of teachers' roles and the competencies required of them.
- **Building Teachers' Capacities:** There is a need for sustainable training programs that help teachers work effectively in educational environments that increasingly rely on AI.
- **The Emergence of a Triadic Interaction:** Educational interaction has taken on a triadic nature, bringing together the teacher, the learner, and the AI system, which plays a growing role in teaching, learning, and assessment.
- **Evolution of the Teacher's Professional Role:** Teachers should be empowered to take on new roles, most notably the collaborative production of knowledge, mentoring, and fostering responsible citizenship in the age of AI.
- **Promoting Social and Ethical Awareness:** Teachers must possess a human-centered awareness of the social and ethical implications of AI use.
- **Developing AI Competencies:** The AI Competency Framework for Teachers aims to enhance their ability to understand AI, adapt to its evolution, and use it responsibly in education.

4. Generative AI Models:

Hamed (2022) notes that generative artificial intelligence encompasses a diverse range of models that differ in their structure, functions, and areas of application; its applications are not limited to text generation but extend to the generation of images, multimedia content, and even the design of molecules and proteins. The most prominent of these models can be classified into six main types, as follows:

Pre-trained Generative Transformer (GPT) Model:

GPT is a language model based on a transformer architecture that relies on sequential prediction of linguistic tokens to produce coherent text. It is designed to be adaptable to a wide range of linguistic tasks, such as translation, summarization, question answering, and text generation.

Language Model for Dialogue Applications (LaMDA):

It is a transformer-based language model developed to generate high-quality, natural-sounding text in conversational contexts. It is characterized by its focus on understanding the nature of open-ended dialogue and maintaining the coherence of responses and the context of the conversation, making it suitable for applications involving human-AI interaction.

GPT-4 Model:

GPT-4 represents an advanced generation of GPT models and is distinguished by its ability to process multimodal inputs—particularly text and images—while generating textual outputs. It is based on a transformer architecture and relies on predicting the next token in the input sequence. Its development also involves fine-tuning processes aimed at improving the model's output to meet desired standards in terms of accuracy, appropriateness, and safe behavior.

The DALL-E Model:

DALL-E is a multimodal generative model that enables the conversion of natural language descriptions into new images and visual outputs. It is particularly notable for generating images and artwork based on textual instructions provided by the user.

Stable Diffusion Model:

This is a generative model primarily used to convert text into images. It relies on diffusion models that start from a state containing a certain amount of noise, then gradually refine and guide it until the resulting image matches the input text description, allowing for the production of diverse images based on linguistic instructions.

ProGen Model:

ProGen is a generative model specialized in the field of proteins. It has been trained on a large number of protein sequences to generate new protein sequences based on specific properties or specifications. This type of model demonstrates the breadth of generative AI, extending it to specialized scientific fields beyond the generation of text and images.

Accordingly, it is clear that generative AI models vary depending on the type of data they process and the nature of the outputs they produce; some focus on generating text and dialogue, while others specialize in producing images and visual content; meanwhile, the applications of other models extend to specialized scientific fields, reflecting the broad scope of generative AI and its diverse potential across various domains.

5. Problem-Based Learning

Problem-based learning is a modern educational strategy that places the learner at the center of the educational process by presenting realistic educational situations or problems that require the learner to apply their knowledge and skills in research, inquiry, analysis, and critical thinking to

arrive at appropriate solutions. This style of learning is not limited to the acquisition of knowledge but focuses on applying it in meaningful situations, thereby enhancing the learner's ability to think systematically and make appropriate decisions.

Problem-based learning also contributes to the development of a range of higher-order thinking skills, particularly critical and creative thinking, by engaging learners in analyzing problems and identifying their dimensions, searching for relevant information, examining and interpreting it, discussing different ideas and alternatives, and then evaluating solutions to arrive at the most appropriate one. Thus, this learning approach enables learners to engage with complex cognitive situations in an active and collaborative manner, and it fosters their independence in learning and their ability to apply knowledge to new situations.

Furthermore, problem-based learning provides a stimulating learning environment; as learning is linked to real-world situations that spark the learner's curiosity and encourage active participation in constructing their knowledge. This can help increase their motivation to learn and strengthen their skills in inquiry, interpretation, collaboration, and decision-making, as well as develop their ability to solve problems systematically and creatively. (Bawadi, 2026)

6. The Relationship Between Problem Solving and Generative Artificial Intelligence:

By reviewing the points raised by (Hamed, 2022) regarding the relationship between an AI-generated electronic discussion environment and problem-solving, we can conclude that the relationship between problem-solving and generative artificial intelligence is complementary and interactive; Generative AI does not replace the learner's problem-solving skills, but rather can provide a supportive environment and cognitive tools for practicing and developing them.

This relationship is reflected in the fact that problem-solving requires a set of mental processes, such as understanding and analyzing the problem, gathering information, evaluating alternatives, generating ideas, testing solutions, and making decisions. These processes can benefit from generative AI's capabilities in analyzing information, generating multiple alternatives, proposing ideas and solutions, and simulating different perspectives. Conversely, the educational value of these tools remains tied to the learner's ability to examine, critique, and verify the AI's outputs and select the most appropriate solution.

Furthermore, integrating generative AI into online discussions broadens the scope of the interaction, transforming the discussion from a mere exchange of ideas among learners into an interactive environment where learners can use AI to generate questions, ideas, and alternative solutions, and then discuss and analyze them with others. In this way, participation, collaboration, and the exchange of perspectives are integrated with AI's capabilities in content generation and data analysis, thereby supporting critical, analytical, and creative thinking.

Consequently, the relationship between problem-solving and generative artificial intelligence is defined by the fact that the latter provides cognitive and interactive support for the various stages of the problem-solving process—through data analysis, the generation of ideas and alternatives, and the broadening of thinking—while the learner takes charge of the processes of examination, critique, comparison, evaluation, and decision-making; Consequently, the conscious educational use of generative artificial intelligence can transform problem-solving from a limited individual activity into an interactive learning process based on generation, discussion, analysis, evaluation, and innovation.

Challenges in the Use of Generative AI Applications in Education.

7. Direct Evidence of GenAI Integration into PBL

Direct empirical evidence regarding the relationship between GenAI and PBL began to emerge more clearly during 2025 and 2026, making the topic very recent and suitable for an international article.

Huang et al. (2025) presented a two-level personalized model of problem-based learning supported by generative AI and applied it to 62 college students in a quasi-experimental design. The results showed that the GenAI-supported model outperformed traditional PBL in reading performance and motivation, noting that the model's effectiveness was more pronounced among students with high levels of engagement.

This finding suggests that GenAI can address one of the traditional challenges in PBL: the difficulty of providing appropriate guidance and feedback to all learners in a timely manner. However, this finding raises an even more important question: Should AI provide the solution or the explanation, or should it provide the scaffolding that helps the learner arrive at it?

In a direction more closely related to problem-solving, Lim et al. (2025) developed a GenAI-supported educational simulation based on PBL principles within the framework of design-based research. The GenAI-supported simulation was compared to a rule-based simulation and a text-based scenario, and the results showed a significant improvement in problem-solving skills among the two simulation groups compared to the text-based scenario. and students also reported a positive perception of the simulation's realism and their immersion in it due to the dynamic nature of their interaction with intelligent agents.

8. Challenges in Deploying Generative Artificial Intelligence in Problem-Based Learning

The use of generative AI in education represents a promising shift; however, its effective integration remains linked to a range of technical, pedagogical, and ethical challenges. The most notable of these can be summarized as follows:

- **Weak infrastructure and the digital divide:** Generative AI applications require advanced technical infrastructure and financial resources that may not be equally available across educational institutions, which could widen the digital divide.
- **The need for training and professional development:** The effective use of these applications requires training teachers, learners, and administrators, equipping them with the skills to utilize and integrate them purposefully into educational practices and curricula.
- **Development of Appropriate Educational Content:** The educational value of artificial intelligence is not realized simply by using its tools; rather, it requires the design of interactive and engaging content that aligns with learning objectives and the principles of effective instructional design.
- **Privacy and Data Security:** The collection and processing of personal data by AI applications raise concerns regarding the protection of learners' and teachers' information, necessitating the establishment of clear mechanisms for security, privacy, and data governance.
- **Preserving Human Interaction:** The use of AI should not undermine the educational relationship between teachers and learners, as this relationship is a fundamental element in fostering learning, providing support, and offering guidance.
- **Equity and Equal Opportunity:** Disparities in access to digital technologies and resources may lead to unequal opportunities to benefit from AI, necessitating policies that ensure equitable access to these technologies.
- **Resistance and Digital Culture:** The adoption of AI may face resistance from some

educational stakeholders due to a lack of experience, feelings of inadequacy, or fear of change.

Risk of Overreliance: Overuse of AI may undermine learners' intellectual independence and critical thinking skills; therefore, it should be used as a tool to support the educational process rather than as a substitute for teachers or human interaction.

1. **Ethical Concerns:** The use of generative AI is linked to issues such as bias and discrimination, content reliability, academic integrity, and the potential for misuse of

these tools, which requires clear ethical and regulatory frameworks. (Mishnan and Bin Qasir, 2025)

It is clear from the above that the challenges of employing generative AI in education are not limited to technical aspects but extend to pedagogical, ethical, regulatory, and social dimensions. Therefore, its successful integration requires providing an appropriate infrastructure, training educational stakeholders, and ensuring data security and digital equity, in addition to establishing ethical and pedagogical safeguards that prevent overreliance on it, thereby ensuring its use as a means to enhance the quality of education and foster learners' development, while preserving the central role of the teacher and human interaction.

9. Artificial Intelligence and Its Impact on Curricula and Teaching Methods: The use of artificial intelligence in education has become a key factor in rethinking curriculum design and teaching methods, as it has facilitated the transition from traditional educational models to more flexible, adaptive models that respond to individual differences among learners. This shift requires the development of curricula that allow for the use of smart technologies in a way that aligns with learners' needs and abilities, as well as the requirements of the contemporary educational environment (OECD, 2022, p. 22).

The integration of artificial intelligence into the educational process has opened up a range of possibilities, most notably:

Personalization of learning paths: Smart systems can analyze learners' performance and needs, enabling the provision of learning paths and activities tailored to their abilities, readiness, and levels of progress.

Diversification of educational content: AI enables the production and use of multimedia educational content, including interactive videos, digital simulations, and interactive activities, which enriches the learning experience and makes learning more engaging.

Analysis and Evaluation of the Educational Process: AI applications provide analytical tools that help monitor learner performance and continuously measure the effectiveness of curricula and teaching methods, thereby supporting data-driven educational decision-making (UNESCO, 2021, p. 118).

AI has also expanded teachers' capabilities to adopt innovative teaching methods by utilizing project-based learning, virtual simulations, interactive learning, and other practices that enhance learner engagement and support active learning. Thus, the impact of AI is not limited to modernizing educational tools; it extends to reimagining curricula and teaching methods to make them more flexible, personalized, and interactive, and enhances the ability of educational institutions to respond to rapid changes in the educational and digital environments.

10. The Role of Artificial Intelligence in Enhancing the Learner Experience:

AI contributes significantly to the development of the educational system for students by facilitating access to data and personalizing the learning process, as evidenced by the following areas:

Adaptive learning: Tailoring educational content to a student's learning pace and academic record to improve their performance and overcome learning obstacles.

Continuous and Flexible Learning: Providing interactive tools that help strengthen self-directed

learning skills and offer feedback beyond the classroom and at any time.

Responding to Inquiries: Providing immediate answers to frequently asked questions through an automated response system, thereby reducing the time spent searching for information. (Abdulhakim, 2025)

11. **Toward a Proposed Pedagogical Framework for Problem-Based Learning Mediated by Generative Artificial Intelligence:**

Through an analysis of the literature and recent studies, we can propose and construct a model for problem-based learning mediated by generative artificial intelligence, as shown in the following table:

Stage	Role of the Learner	Role of Generative AI	Role of the Teacher
Problem Identification	Understanding the problem and identifying its components	Asking exploratory questions and offering its alternative perspectives	Guiding the Learner Without Providing the Solution
Investigation	Researching, gathering, and analyzing information	Suggesting sources, ideas, and questions	Verifying the quality of sources

Generating alternatives	Formulating Hypotheses and Solutions	Generating multiple alternatives and simulating scenarios	Organizing discussion and comparison
Critiquing solutions	Examining and verifying outputs	Providing explanations and alternatives	Training learners to verify and critique
Building solutions and reflecting	Making, Justifying, and Evaluating Decisions	Providing feedback	Assessing learning and fostering reflection

12. Principles for Incorporating Generative Artificial Intelligence into Problem-Based Learning

The most important pedagogical principles for the use of generative AI in problem-based learning can be summarized as follows:

1. Learner-centered approach: Preserving the learner's role in analyzing the problem, generating hypotheses, evaluating alternatives, and making decisions, so that AI does not replace their cognitive activity (Kasneci et al., 2023; Wang et al., 2024).
2. Cognitive scaffolding: Using AI to provide hints, questions, alternatives, and feedback, rather than ready-made solutions, thereby supporting independent and active learning (Huang et al., 2025; Lim et al., 2025).
3. Critique and Verification: The need to examine AI outputs, compare them with reliable sources, and verify their accuracy, thereby fostering critical thinking and awareness of the limitations of these technologies (Kasneci et al., 2023; UNESCO, 2024).
4. Interaction and Collaboration: Using AI to enrich dialogue and generate alternatives while maintaining interaction between learners and the teacher and fostering collaborative knowledge-building (Otto et al., 2025; Scholkmann et al., 2025).
5. Human Supervision: The teacher remains a central figure in designing the learning environment, guiding the use of AI, and monitoring and assessing learning (UNESCO, 2024).
6. Transparency and academic integrity: Establishing clear guidelines for the use of AI, promoting transparency and disclosure regarding its use, and upholding academic integrity (Yusuf et al., 2024; Zhang et al., 2024).
7. Equity and Data Protection: Ensuring equal access to AI technologies, while protecting

learners' data and privacy and reducing the digital divide (UNESCO, 2024).

Accordingly, the effective use of generative AI in problem-based learning relies on the integration of the learner as a cognitive agent, the teacher as a guide and supervisor, and AI as a scaffold and cognitive mediator, thereby enhancing critical thinking, problem-solving, and collaborative learning, without becoming a substitute for the learner's mental activity.

Conclusion

Our analysis of studies and the literature reveals that generative artificial intelligence opens up educational possibilities for problem-based learning that go beyond the limits of traditional technical support, as it can contribute to enriching the stages of problem analysis, generating ideas and alternatives, providing feedback, tailoring support, and fostering interaction and engagement in more dynamic and authentic learning situations. However, the educational value of these possibilities is not determined by the presence of the technology itself, but rather by how its use is designed within the learning situation.

The analysis has shown that the relationship between generative AI and problem-based learning should not be based on technology replacing the learner's mental activity, but rather on the integration of AI capabilities with the learner's cognitive and social abilities.

Consequently, the most balanced approach involves using GenAI as a cognitive scaffold and a learning mediator, helping learners ask questions, explore alternatives, expand their scope of thinking, and test hypotheses—without relieving them of the responsibility for analysis, critical thinking, verification, and decision-making.

This approach also reveals a fundamental shift in the roles of the participants in the educational process; the learner becomes more responsible for constructing knowledge and assessing its quality, while the teacher transitions from the role of a knowledge transmitter to that of a designer, facilitator, guide, and organizer of interactions between the learner, the problem, peers, and artificial intelligence. Conversely, the educational problem becomes the focal point for generating and negotiating knowledge, while artificial intelligence serves as a mediating element within the pedagogical framework rather than an ultimate source of truth.

Consequently, the transition from “AI-supported problem-based learning” to “generative AI-mediated problem-based learning” represents a significant conceptual shift; it shifts the focus from the question of how to use the tool to a deeper question concerning how to redesign the learning activity itself in a way that preserves the essence of active learning, critical thinking, autonomy, and collaborative knowledge construction. From this perspective, the future of employing generative AI in PBL is not tied to its ability to produce solutions more quickly, but rather to its ability to make learners more capable of thinking, inquiring, critiquing, justifying, and learning independently.

Recommendations:

In light of the findings of the theoretical analysis, the following recommendations can be

proposed:

1. Redesign problem-based learning activities to allow for the use of generative AI as a cognitive scaffold, while maintaining the learner's responsibility for analyzing the problem and constructing the solution.
2. Develop clear pedagogical models that specify when and how learners can use artificial intelligence during the stages of problem-based learning, and establish clear boundaries between cognitive support and the complete replacement of mental activity.
3. Restructure teacher training programs to develop teachers' competencies in artificial intelligence, instructional design, stimulus engineering, verification of generative model outputs, and assessment based on thinking and process rather than just the final product.
4. Foster a culture of critical thinking among learners regarding AI outputs by training them to verify information, identify errors and biases, compare alternatives, and provide evidence to justify their choices.
5. Reconsider assessment methods in AI-supported PBL environments so that they focus on the processes of thinking, inquiry, analysis, justification, and reflection, rather than being limited to evaluating the final product.
6. Establish clear institutional and ethical frameworks to regulate the use of generative AI, ensuring academic integrity, data protection and privacy, and transparency in the use of AI tools.
7. Preserve the human and collaborative dimension of learning, and prevent AI from undermining dialogue among learners or the educational relationship between teachers and learners.
8. Ensure digital equity and equal access to AI technologies by developing digital infrastructure and providing resources, equipment, and training in a fair manner.
9. Encourage experimental and comparative studies that test the effectiveness of problem-based learning models mediated by generative artificial intelligence, while examining their effects on critical thinking, problem-solving, creativity, autonomy, motivation, and collaborative learning.
10. Study the long-term use of generative artificial intelligence to identify its potential effects on intellectual independence, higher-order thinking skills, and the ability to solve problems without direct technological assistance.

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