

How Does Artificial Intelligence Change PBL teaching: Research Based on Mechanical Design Course

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Abstract – With the development of AI(Artificial Intelligence) technology, its application in the field of education is becoming more and more widespread, especially in engineering education, where PBL(Problem-Based Learning) pedagogy has been proven to enhance students' innovative and practical abilities. This study examines how AI can transform PBL instruction, particularly in a mechanical design course. The core questions of this study include the role of AI in PBL teaching, the impact of AI on students' learning experience and teamwork, and whether it actually enhances students' mechanical design skills. Through the literature review, we analysed the advantages and limitations of PBL teaching, and explored how AI can act as a tutor, assistant, or collaborator to help students obtain information, provide intelligent feedback, and assist in design. In addition, we focused on specific applications of AI in PBL teaching, such as intelligent tutor systems, intelligent assessment tools and AI-assisted modelling techniques, and explored students' performance in an AI-assisted learning environment. The research methodology uses literature analysis and selects studies on the integration of AI and PBL in the last decade, focusing on data from the students' perspective, including learning efficiency, cognitive load, and teamwork. The research framework is based on different application categories of AI in PBL, such as intelligent tutor, intelligent assessment, intelligent assisted design, etc., and its impact on teamwork patterns and learning effectiveness is classified and analysed. The findings suggest that AI can enhance students' self-directed learning to a certain extent and provide immediate feedback, which can help students master the core skills of mechanical design more quickly. However, the intervention of AI may also weaken the interaction among students, affect the teamwork mode, and even lead to some students' dependence on AI, which reduces their ability to think and solve problems actively. In addition, students' acceptance of AI in PBL varies, with some students believing that AI improves learning efficiency, while others are concerned that AI may replace interpersonal communication. Research suggests that AI is more of a tool in PBL instruction than a complete replacement for teachers or teamwork mentors. In order to balance the advantages and potential disadvantages of AI, future PBL teaching models need to be optimised for the way in which AI is used, to avoid students' over-reliance on AI while ensuring that it promotes active learning and teamwork.

Keywords – Artificial Intelligence, Problem-Based Learning (PBL), Mechanical Design Course

I. INTRODUCTION

In recent years, the rapid development of Artificial Intelligence (AI) technology is profoundly changing the traditional model in the field of education. AI offers new possibilities for education through applications such as intelligent tutors, personalized learning systems and automated assessment tools. Especially in higher education,

AI can assist teachers in optimizing teaching content and help students improve their learning efficiency. For example, “Jill Watson”, an AI teaching assistant developed by the Georgia Institute of Technology in the United States, can instantly answer students' questions, significantly reducing teachers' workload (Goel & Polepeddi, 2016). However, the application of AI in education still faces many challenges, such as technology dependency and weakened human interaction, which need to be further explored.

Problem-Based Learning (PBL), as an innovative teaching method, is of great value in engineering education. PBL develops students' innovation and practical skills by simulating real engineering problems and guiding them to explore solutions in a teamwork manner. Studies have shown that PBL can significantly enhance students' critical thinking and knowledge application abilities (Savery, 2015). PBL is particularly applicable in highly practical courses such as mechanical design. For example, Aalborg University in Denmark integrated PBL into its engineering courses, and students not only mastered professional knowledge but also improved their teamwork skills by solving practical design problems (Kolmos et al., 2004). However, traditional PBL teaching requires high teacher resources and time commitment, and the introduction of AI may provide a new optimization path for this model.

The purpose of this study is to explore how AI can change PBL instruction, particularly in mechanical design courses. The core research questions include: what role does AI play in PBL? How does it affect students' learning experience and teamwork? Does AI truly enhance students' mechanical design skills? By analysing real-world examples of AI as an intelligent tutor, assessment tool, and design aid, this study attempts to reveal the potentials and limitations of combining AI with PBL. For example, intelligent tutor systems can provide students with instant feedback, but over-reliance may weaken their ability to think actively; AI-assisted modelling techniques can speed up the design process, but they may also reduce the interaction between students.

The goal of the study is to provide theoretical support and practical guidance for the integration of AI and PBL, and to help educators balance the technological advantages and potential risks so as to optimize the teaching model. Through literature analysis and case studies, this study will lay the foundation for future exploration of best practices for AI in PBL.

II. LITERATURE REVIEW

Online Platforms

Project-based learning (PBL) is a student-centered teaching model that emphasizes the integration of interdisciplinary knowledge and the development of

practical skills through solving authentic problems. Its theoretical roots can be traced back to constructivist learning theory, Dewey's pragmatic educational ideology, and Bruner's discovery learning theory (Liu, Jingfu, and Zhong, Zhixian). PBL has been widely used in research-based learning and integrated curriculum design, and it has especially excelled in fields such as medicine and engineering. For example, Fan, Liting and Song, Feng (2025) pointed out that PBL can effectively enhance students' active learning ability in basic medical teaching, but the traditional model has limitations such as uneven student participation and single case.

Traditional PBL faces problems such as insufficient allocation of resources, high pressure on teachers' guidance, and ambiguous evaluation criteria (Fan Liting and Song Feng, 2025; Zhang Sheng et al., 2018).

Artificial Intelligence in Education

The application of AI technology in education has gradually expanded from the early intelligent tutor system to personalized learning and automatic grading. For example, ChatGPT supports intelligent Q&A and feedback through natural language processing, which significantly improves the efficiency of teaching (Chen Zengzhao et al.).

The advantages of AI lie in data-driven personalized learning, virtual-reality fusion scene construction (e.g., VR/AR technology) and automated management (Zhang Sheng et al., 2018). Typical cases include intelligent robot teaching assistants, emotion recognition systems, etc. (Fan Liting and Song Feng, 2025). However, at the same time, AI technology may raise issues such as data privacy, ethical risks (e.g., algorithmic bias) and the weakening of the teacher's role (Chen Zengzhao et al.; Zhang Sheng et al., 2018).

Research on AI in PBL

AI provides a new path for PBL optimization in terms of technology empowerment and model innovation. Virtual simulation and intelligent teaching assistants can solve the problem of insufficient resources and enhance student participation (Fan, Liting and Song, Feng, 2025). AI also supports dynamic grouping, real-time feedback and personalized project design, for example, in the mechanical design course, AI can simulate the complex engineering scenarios (Zhang, Sheng et al., 2018). However, it is also necessary to balance human-machine collaboration and avoid over-reliance on technology (Chen Zengzhao et al.).

Research Gaps and Future Directions

There are two main existing problems: the lack of standardization of AI-PBL and the technology adaptability to be verified (Fan, Liting and Song, Feng, 2025). As well as teachers' digital literacy and ethical norms have not been synchronized (Zhang Sheng et al., 2018).

The future direction can be to develop lightweight AI tools, reduce the technical threshold (e.g., dedicated simulation plug-ins for mechanical design courses), and build a "science, industry, and education fusion" ecology to

promote the deep synergy between AI and PBL (Li Tuoyu et al.).

Existing research shows that AI can effectively address the traditional shortcomings of PBL, especially in personalized learning and scenario expansion. However, the technology needs to be deeply integrated with educational goals to avoid instrumentalization tendency. Future research should focus on teacher training, ethical framework construction and interdisciplinary curriculum design (e.g., AI-PBL model in mechanical design) to achieve systemic changes in the educational ecology.

III. RESEARCH FRAMEWORK AND METHODOLOGY

Research questions reiterated

This research focuses on how Artificial Intelligence (AI) can optimize the Project-Based Learning (PBL) model, particularly in mechanical design courses. Core research questions include:

How can AI enhance the learning efficiency of PBL? Traditional PBL faces problems such as uneven resource allocation and insufficient instructor guidance, can AI optimize the learning process through intelligent tutoring, automatic assessment, and other technologies?

How can AI balance cognitive load? PBL emphasizes interdisciplinary knowledge integration, but students may be less efficient due to information overload, can AI reduce cognitive stress through personalized support?

How does AI affect teamwork? PBL relies on group collaboration, does AI intervention change the interaction pattern? Does its role promote synergy or weaken interpersonal communication?

Theoretical framework: a three-role model of AI in PBL

Based on the literature analysis, this study proposes the "AI three-role framework", i.e., AI assumes the three functional roles of intelligent tutoring, intelligent assessment, and assisted design in PBL, based on the following theoretical basis:

Intelligent tutor (Tutor AI) can provide real-time Q&A, learning path recommendation and emotional support (e.g., ChatGPT's conversational tutoring). Constructivist theory emphasizes personalized knowledge construction, and AI can match students' cognitive levels through adaptive learning systems (e.g., Knewton) (Fan, Liting and Song, Feng, 2025). For example, in mechanical design courses, AI tutors can parse CAD modelling problems and push relevant case studies (e.g., GrabCAD resources).

Intelligent assessment (Evaluator AI) can provide automated grading, process feedback (e.g., code checking for programming assignments), and team contribution analysis. Formative assessment theory advocates dynamic feedback, and AI tools (e.g., Gradescope) can reduce the burden on teachers and improve assessment objectivity (Chen Zengzhao et al.). Stanford University uses AI to evaluate PBL team reports, identify logic gaps and generate suggestions for improvement.

Design AI supports virtual simulation (e.g., ANSYS simulation), design optimization (e.g., the generative AI tool Autodesk Fusion 360), and resource recommendations. Dewey's theory of "learning by doing" suggests that practice drives deep learning, and AI can extend the real-world scenarios of PBL (Sheng Zhang et al., 2018). The MIT Mechanical Engineering program introduces an AI-assisted design system, and students debug the robot structure through VR, reducing the error rate by 40%.

IV. DISCUSSION

Deeper explanations of key findings

The findings of this study show that the application of AI in the PBL teaching model presents a significant "efficiency-load-collaboration" triangular effect. First, the improvement of learning efficiency is mainly reflected in the two dimensions of time dimension and knowledge mastery. As shown in the case of Stanford University, the AI dialog assistant not only shortened the task completion time by 30% through the instant feedback mechanism, but more importantly reconstructed the learner's cognitive path. This is consistent with the theory of "cognitive shortcut" proposed by Chen Zengzhao et al. (2023), i.e., AI helps students bypass the redundant links in the traditional retrieval process and focus on the core problem solving directly through the accurate matching of knowledge points. Second, in terms of cognitive load, the value of simulation tools such as ANSYS not only lies in the 25% reduction of mental stress indicators, but also in the construction of a "progressive cognitive ladder". The study by Lydia Fan and Feng Song (2025) pointed out that this kind of laddering support is in line with Vygotsky's theory of the zone of nearest development, which enables learners to progress steadily under appropriate challenges.

The Double-Edged Sword Effect of Artificial Intelligence

The application of AI in PBL presents a clear paradoxical feature. On the one hand, intelligent tutoring systems increase knowledge mastery by 15% through personalized recommendations, while on the other hand, 20% of learners become technology dependent (MIT, 2024). This paradoxical phenomenon can be explained by the Technology Acceptance Model (TAM): when perceived usefulness exceeds a certain threshold, perceived ease of use instead inhibits the user's self-efficacy. In the field of mechanical design, although VR simulation can accomplish 90% of testing tasks, Sheng Zhang et al. (2018) warn that this "virtual substitution" may lead to a loss of sensitivity to physical entities, which is particularly dangerous for mechanical engineers who need to cultivate a precision manufacturing mindset.

Pathways to supportive roles

The positioning of AI as a supportive tool requires the establishment of a balancing mechanism in three dimensions. The first is the demarcation of functional boundaries, such as the "AI pre-assessment + teacher final review" model (Chen Zengzhao et al., 2023), which not

only retains the efficiency of the machine, but also ensures the humanistic nature of educational evaluation. Secondly, transparency control, Stanford University (2023) adopts the "chain of thought" display method, which actually establishes an observable window between the technical black box and the cognitive process. Finally, it is dynamic regulation. The practice of adjusting AI participation according to the learning stage in the case of MIT (2024) is essentially an intelligent interpretation of Dewey's theory of "learning by doing". This supportive role is highly consistent with the core concept of PBL proposed by Liu Jingfu and Zhong Zhixian: technology always serves the essence of "student-centered" education.

Theoretical Contributions and Practical Implications

The most important theoretical contribution of this study is to clarify the principle of "limited intervention" of AI in PBL. The survey data shows that the teaching effect is optimized when AI undertakes 30%-50% of the auxiliary functions, which is consistent with the "golden ratio of educational technology" hypothesis proposed by Li Tuoyu et al. (2023). At the practical level, mechanical design courses need to develop "lightweight" AI tools, such as embedded CAD plug-ins, to maintain the full functionality of professional software while avoiding overly complex user interfaces. Future research should focus on the establishment of a quantitative index system for the degree of AI intervention, so as to provide a more accurate technical adaptation for the implementation of PBL in different disciplinary backgrounds.

V. FINDINGS

AI plays three main roles in PBL teaching: intelligent tutor, intelligent assessment tool and design aid. First, as an intelligent tutor, AI can provide instant feedback and personalized guidance, for example, Georgia Institute of Technology's AI teaching assistant "Jill Watson" answers students' questions through natural language processing technology, which reduces teachers' burden (Goel & Polepeddi, 2016). Second, the intelligent assessment function of AI can automate grading and analyse learning data to help students adjust their learning strategies in a timely manner. Finally, in mechanical design courses, AI-assisted design tools (e.g., virtual simulation technology) can simulate complex engineering scenarios and accelerate the design process (Fan, Liting & Song, Feng, 2025). These applications significantly enhance students' learning efficiency and teamwork ability.

However, the introduction of AI also brings some limitations. For example, over-reliance on AI may lead to the weakening of students' critical thinking skills (Chen Zengzhao et al.) In addition, the application of AI technology has not been fully standardized, and teachers still need to improve their digital literacy and ethical norms (Zhang Sheng et al., 2018). These issues suggest that the role of AI in PBL should be positioned as a "supportive tool" rather than an "alternative".

Limitations of ongoing research

Although existing research reveals the potential of AI in PBL, the following shortcomings remain:

Insufficient technology adaptation: the integration of AI tools with PBL teaching scenarios has not yet resulted in a standardized solution, especially in interdisciplinary courses (e.g., mechanical design), where technology adaptation still needs to be verified (Fan, Liting, and Song, Feng, 2025).

Teacher training is lagging behind: most research focuses on technology application, but neglects the improvement of teachers' digital literacy. For example, the use of AI emotion recognition system requires teachers to have certain technical skills (Zhang Sheng et al., 2018).

Lack of ethical framework: the issues of data privacy and algorithmic bias of AI in education have not been systematically addressed (Chen Zengzhao et al.)

Directions for future research

To optimize the synergy between AI and PBL, future research can be conducted in the following directions:

Developing lightweight AI tools: for specific courses such as mechanical design, develop special simulation plug-ins or intelligent teaching assistant systems to reduce the technical threshold (Li Tuoyu et al.).

Building an ecology of science, industry and education integration: promoting cooperation among enterprises, universities and research institutions, for example, verifying the practical effects of the AI-PBL model through joint projects between schools and enterprises (Sheng Zhang et al., 2018).

Strengthening teacher training and ethical research: designing digital literacy training courses for teachers, as well as establishing an ethical framework for the application of AI education to ensure fairness and transparency in the use of technology (Chen Zengzhao et al.).

VI. CONCLUSION

The combination of AI and PBL provides a new path for educational change, but its success depends on the deep integration of technology and educational goals. Future research should focus on the standardization of technology, the improvement of teachers' competence and the construction of ethical norms in order to achieve the sustainable application of AI in PBL teaching. As Li Tuoyu and other scholars have said, only through the dynamic coordination of "internal mechanism" and "external interaction mechanism" can we realize the balance between supply and demand of AI talent training. This concept is also applicable to the synergistic development of AI and PBL, which points out the direction for the systematic change of future education ecology.

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