International Journal of Learning, Teaching and Educational Research
Vol. 25, No. 6, pp. 372-392, June 2026
https://doi.org/10.26803/ijlter.25.6.15
Received Mar 13, 2026; Revised May 12, 2026; Accepted May 12, 2026

Project-Based Learning in the Age of Generative AI: Developing Student Autonomy and Creative Problem-Solving in Software Engineering Education

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Abstract. The rapid development of generative artificial intelligence (AI) has begun to influence learning practices in higher education, raising important questions about how to maintain students' independent thinking and creative problem-solving skills. In this context, project-based learning (PBL) is increasingly viewed as a pedagogical approach that can encourage active participation and support the development of applied competencies. This study explores the potential of PBL to strengthen student autonomy, creativity, and professional competence in software engineering education within an academic environment where generative AI tools are widely available. The research involved 83 master's students enrolled in computer science and software engineering programs at a university in Kazakhstan. A mixed-method design was used, combining qualitative analysis of student projects and reflective reports with descriptive survey data. Over a 30-week period, these

Citation: Balakayeva, G., Zeinolla, S., Akzhalova, A., & Kalmenova, G. (2026). Project-Based Learning in the Age of Generative AI: Developing Student Autonomy and Creative Problem-Solving in Software Engineering Education. *International Journal of Learning, Teaching and Educational Research*, *25*(6), 372–392. https://doi.org/10.26803/ijlter.25.6.15

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students completed both individual and team-based projects addressing practical technological tasks in software engineering and computing, including the development of mobile and web applications, AI-generated solutions, data analytics tools, and scientific modelling systems. The results indicate that PBL contributed to the development of practical programming skills, independent learning skills, and research-oriented problem solving. Students' reflective reports completed project outcomes, presentations, and survey responses indicated increased autonomy, stronger engagement with applied tasks, and a clearer understanding of theoretical concepts through implementation. Many students also noted that the requirement to develop functional systems and justify technical decisions made exclusive reliance on ready-made AI-generated solutions more difficult. The findings suggest that structured PBL can help sustain meaningful cognitive engagement and support competence development in software engineering education where generative AI tools are widely available.

Keywords: project-based learning; generative AI; higher education; student autonomy; software engineering

1. Introduction

The rapid development of generative artificial intelligence (AI) tools is transforming learning practices in higher education. Chatbots and automated text-generation systems provide students with immediate access to explanations, summaries, programming examples, and structured academic content. These tools can support learning efficiency and help students process complex information, but they also create new pedagogical challenges.

Despite these advantages, the growing use of generative AI tools raises concerns about students' reliance on ready-made answers. Studies on educational chatbots and AI-supported learning indicate that such tools can support access to information and task completion, but they should complement rather than replace students' independent cognitive engagement (Kumar, 2021; Chistyakov et al., 2023). When students rely excessively on AI-generated outputs, their participation in deeper processes of analysis, synthesis, and creative problem-solving may be weakened. However, it remains insufficiently explained how structured project-based learning (PBL) can help preserve students' autonomy and creative problem-solving in software engineering education where generative AI tools are widely accessible.

In this study, PBL in the context of generative AI is not understood as a simple replacement for traditional teaching methods or as a complete solution to AI-related learning challenges. Rather, it is operationalized as a structured pedagogical design in which students are required to formulate a problem, develop a functional software product, test the solution, prepare documentation, reflect on their contribution, and defend technical decisions. This structure shifts the learning focus from obtaining ready-made AI-generated answers to demonstrating understanding, adaptation, and responsibility for the final project outcome.

In response to these challenges, PBL is relevant to the competency-based paradigm because it requires students to apply theoretical knowledge in solving complex practical problems. In this study, PBL is considered as an active learning approach that supports applied competence, autonomy, and creative problem-solving in software engineering education (Balakayeva & Zeinolla, 2022). PBL is widely used in higher education because it organizes learning around real-world problems and practical outcomes. In PBL environments, students analyze problems, design solutions, create applied products, and justify their decisions, all of which support deeper engagement with learning content (Kokotsaki et al., 2016; Ngereja et al., 2020).

In engineering and computing education, PBL is especially relevant because it supports collaboration, creativity, inquiry-oriented learning, and professional problem-solving. Students work with complex tasks, distribute responsibilities, test alternative solutions, and present final outcomes, which can strengthen autonomy and applied competence (Chen et al., 2020; Johnsen et al., 2024; Zhang & Ma, 2023; Crawford et al., 2024). In the present study, this interdisciplinary orientation was reflected in Master's programs in Computer Science and Software Engineering, where students worked on projects combining software development, AI, data analytics, computer vision, business digitalization, and scientific modelling.

In the implemented PBL model, students were provided with project guidelines, staged project tasks, instructor consultations, assessment rubrics, final presentations, and reflective reports. These activities were designed to support independent work, collaboration, technical decision-making, and reflection throughout the project process. The present study aims to examine the potential of structured PBL to support students' autonomy, creative problem-solving, and professional competence in a generative AI-rich software engineering context. The novelty of the study lies in considering PBL not only as an active learning method, but also as a pedagogical structure that requires students to develop, test, document, and defend functional software products, thereby making passive reliance on ready-made AI-generated solutions more difficult.

Accordingly, the study addresses the following research questions:
RQ1: How do Master's students in computer science and software engineering perceive the contribution of PBL to autonomy, practical competence, and creative problem-solving?
RQ2: How does the requirement to develop, test, document, and defend functional software products influence students' perceived reliance on AI-generated solutions?
RQ3: What features of the implemented PBL model appear to support deeper cognitive engagement in a generative AI-rich learning environment?

2. Literature Review

2.1 Conceptual Framework for PBL in Higher Education

Project-based learning has become widely recognized as an effective pedagogical approach in higher education, particularly within the framework of competency-based education. Unlike traditional lecture-based instruction, PBL focuses on the exploration of real-world problems and the development of practical outcomes. Through this process, students are not only exposed to theoretical knowledge but are also encouraged to develop transferable competencies that are essential for professional practice (Almulla, 2020; Feder, 2017). Within the competency-based paradigm, the quality of higher education is increasingly evaluated not only by the volume of knowledge students acquire but also by their ability to apply that knowledge in practical situations and adapt to professional contexts. Project-based learning supports these goals by engaging students in activities that involve decision-making, problem-solving, collaboration, and the application of disciplinary knowledge in authentic settings (Tawfik et al., 2020; Wijnia et al., 2024).

Research also suggests that interdisciplinary projects allow students to integrate perspectives from different academic fields and develop more complex approaches to solving professional problems (Brassler & Dettmers, 2017; Hart, 2019). However, interdisciplinary learning does not occur automatically. Effective integration of knowledge requires careful instructional design, appropriate guidance from instructors, and clear links between project tasks and learning outcomes (MacLeod & van der Veen, 2019). Thus, the value of PBL should not be understood simply as replacing lectures with projects. Its effectiveness depends on how project tasks are structured, how students are supported, and how project outcomes are assessed. This distinction is important for the present study because project participation alone cannot automatically guarantee autonomy, creativity, or deeper learning.

2.2 Learning Outcomes, Motivation, and Collaborative Learning

A considerable body of research has examined the influence of PBL on educational outcomes. Reviews and empirical studies show that PBL can support student learning, motivation, collaboration, and competence development when project tasks are carefully designed and aligned with learning objectives (Kokotsaki et al., 2016; Ngereja et al., 2020; Chen et al., 2020; Johnsen et al., 2024). Studies conducted in STEM and engineering education also indicate that PBL can improve academic achievement while supporting higher-order thinking skills and professional competence (Çelik et al., 2018; Fini et al., 2018).

Participation in project activities encourages students to engage in inquiry processes, including problem analysis, data interpretation, and applied decision-making. As a result, project work contributes not only to the acquisition of knowledge but also to the development of analytical and reasoning skills that are essential in professional environments (Anazifa & Djukri, 2017; Vesikivi et al., 2020). Assessment and feedback are important conditions for effective PBL. Project-based assessment allows students to demonstrate applied competencies and engage more deeply with learning tasks, while transparent learning objectives and continuous feedback support motivation and responsibility for learning outcomes (Gratchev, 2023; Gratchev & Jeng, 2018; Shin, 2018; Rehman et al., 2024; MacLeod & van der Veen, 2019; Pan et al., 2021; Son & Penry, 2022).

Collaboration is another central component of PBL. Group projects provide students with opportunities to develop communication skills, negotiate responsibilities, and coordinate tasks with peers (Li et al., 2022; Monson, 2017). Nevertheless, teamwork can present challenges if group processes are not carefully managed, including unequal workload distribution, coordination difficulties, and interpersonal conflicts (Hussein, 2021; Culclasure et al., 2019). Therefore, collaborative PBL requires structure, monitoring, and support rather than assuming that group work will automatically produce effective learning.

2.3 Creativity, Interdisciplinary Learning, and Educational Challenges

An important aspect of the PBL literature concerns its role in fostering creativity and innovative thinking. Unlike traditional assignments that often require students to reproduce predetermined answers, project-based tasks encourage learners to explore multiple possible solutions, justify their choices, and revise their ideas. Such learning environments support divergent thinking and creative problem-solving. This perspective is closely connected with the concept of "learning by making," which emphasizes active construction of knowledge through practical activities. Creating models, prototypes, or digital artefacts can deepen conceptual understanding by encouraging experimentation and reflection (Tan et al., 2025; Martínez-Rodrigo et al., 2017).

At the same time, the benefits of PBL depend on implementation quality. Researchers frequently highlight issues such as insufficient teacher preparation, unclear assessment criteria, and difficulties in integrating project work into existing curricula (Fini et al., 2018; Al Mughrabi & Jaeger, 2018). Sustainable implementation requires alignment between learning objectives, assessment systems, student support mechanisms, and project activities (Ståhl et al., 2022; Khandakar et al., 2020). Overall, previous studies show that PBL can support creativity, interdisciplinary competence, and professional preparation. However, these outcomes depend on project design, guidance, assessment, and reflection. This point is especially important in the context of generative AI, where students may have access to tools that can produce ready-made explanations, code, or written content.

2.4 Generative AI, Student Autonomy, and PBL

The growing use of digital technologies has influenced PBL environments. Educational chatbots and digital tools can support project work by helping students access information, organize learning activities, and receive explanations. At the same time, researchers caution that such technologies should complement rather than replace students' independent cognitive engagement (Kumar, 2021; Chistyakov et al., 2023). In the present study, generative AI is positioned both as a learning tool and as a potential pedagogical risk. As a learning tool, AI can support students by providing explanations, examples, programming suggestions, and language assistance.

However, when students rely on AI-generated output without sufficient analysis, testing, or reflection, such tools may weaken independent reasoning and reduce meaningful engagement with the learning process. This issue is particularly important in software engineering education, where students may use AI tools to generate code, debug errors, explain algorithms, or prepare documentation. These functions can support learning when students critically evaluate and adapt AI-generated suggestions. At the same time, they may also encourage superficial task completion if students accept generated answers without understanding the underlying logic of the solution.

From this perspective, PBL can be understood as a pedagogical structure that mediates the role of AI in learning. Project-based learning does not remove AI from the educational process, but it changes the conditions under which AI can be used. When students are required to formulate a problem, develop a functional product, test the solution, document the process, and defend technical decisions, AI-generated content becomes only one possible resource within a broader learning process. Therefore, the relationship between PBL and AI should not be interpreted as opposition, but as a question of instructional design. Structured PBL can help shift students from passive dependence on AI-generated outputs toward active evaluation, adaptation, and responsibility for final outcomes.

2.5 Summary and Research Gap
Overall, the literature indicates that PBL contributes to professional competence by increasing student engagement, supporting collaboration, strengthening interdisciplinary integration, and encouraging applied problem-solving. However, these outcomes depend on careful instructional design, clear assessment criteria, continuous feedback, and reflective learning processes (Almulla, 2020; Gratchev, 2023; Vesikivi et al., 2020; Li et al., 2022; Swanson et al., 2019).

Most existing studies focus primarily on academic outcomes, student engagement, collaborative learning, or general competence development in PBL environments. Comparatively less attention has been given to how PBL operates in learning contexts where students can use generative AI tools to obtain explanations, code, and ready-made AI-generated solutions. This limitation is important because AI tools may support learning, but they may also reduce students' need to engage independently with problem analysis, solution design, and technical justification.

Therefore, the research gap addressed in this study concerns the role of structured PBL in supporting student autonomy, creative problem-solving, and professional competence in a generative AI-rich software engineering environment. The study positions AI not only as a technological tool, but also as a pedagogical factor that may influence the depth of students' engagement with project tasks.

3. Methodology
3.1 Research Design
This study examined the implementation of PBL in university-level software engineering education through an applied educational intervention. The purpose of the intervention was to explore how PBL can contribute to the development of applied competencies, research skills, collaboration, and student autonomy among graduate students.

The research followed a mixed-method descriptive post-intervention design. This type of design is commonly used to document the implementation of educational interventions and to examine students' perceived learning outcomes, reflective accounts, and project-based evidence after instruction (Hussein, 2021; Randazzo et al., 2021; Thiem et al., 2023). The intervention was conducted within a single cohort of Master's students, and no control group or pre-intervention measurements were included. Therefore, the findings are interpreted as descriptive evidence of students' experiences and perceived outcomes rather than as causal impact.

The study combined qualitative evidence from student projects and reflective reports with descriptive quantitative survey data. This mixed-evidence approach was used to describe students' responses to the PBL intervention and to document the implementation process. However, the design does not allow causal comparison with traditional teaching methods or statistical claims about the extent of change caused by PBL.

3.2 Educational Context and Participants

The intervention was implemented within three Master's-level courses in software engineering and computing at Al-Farabi Kazakh National University in Almaty, Kazakhstan. These courses focus on areas such as software development, algorithm design, and applied computational problem solving. In these disciplines, students are expected not only to understand theoretical concepts but also to apply them in practical engineering tasks, including programming, system design, testing, and technical documentation.

A total of 83 Master's students enrolled in computer science and software engineering programs participated in the study. Graduate students were selected because they had already completed foundational theoretical training and were therefore capable of undertaking complex applied project work. Previous studies also suggest that PBL is particularly effective at advanced stages of higher education, where students are expected to demonstrate professional orientation and interdisciplinary competence (Fini et al., 2018; MacLeod & van der Veen, 2019).

In modern higher education environments, students have broad access to digital technologies and generative AI tools. While such tools can support learning processes, some studies indicate that excessive reliance on AI-generated solutions may reduce students' engagement in deeper cognitive activities. For this reason, PBL was introduced as a pedagogical approach intended to strengthen independent analysis and critical thinking (Kumar, 2021; Randazzo et al., 2021).

3.3 PBL Intervention and Implementation

The intervention was conducted over a period of 30 weeks, covering an entire academic year. The extended duration allowed students to work on projects through several stages, including planning, development, testing, and revision. Previous research has shown that longer project cycles may lead to stronger competence development compared with short-term assignments (Khandakar et al., 2020; Vesikivi et al., 2020).

Students selected project topics based on their own interests and then refined these ideas in consultation with instructors. Projects were expected to address practical or professional problems relevant to software engineering and digital technologies. Research suggests that tasks connected to real-world contexts can increase students' motivation and enhance the practical value of learning outcomes (Feder, 2017; Rehman et al., 2024). Projects were completed either individually or in small teams. In group projects, students organized their own teams, distributed responsibilities, and coordinated work schedules. Previous studies indicate that the quality of collaboration within project teams can significantly influence learning outcomes and student satisfaction (Li et al., 2022; Monson, 2017).

The project process followed several stages, including problem identification, requirement analysis, project planning, development and testing, documentation, final presentation, and reflective reporting. Such structured stages are commonly used in PBL models within engineering education, as they support systematic project development and improve the quality of both learning outcomes and technical solutions (Fini et al., 2018; Gratchev, 2023; Requies et al., 2018). Since the study was conducted in an educational context where generative AI tools were widely accessible, AI use was considered as part of the learning environment rather than as a separate experimental treatment. Students could use AI tools for support purposes, such as clarifying concepts, searching for examples, debugging, language editing, and documentation support. However, the PBL requirements obliged students to adapt, test, explain, and defend their own project outcomes. Table 1 presents the possible use of AI tools and the required student responsibility across the main project phases.

Table 1: AI Use Across Project Phases

Project phase	Possible AI use	Required student responsibility
Problem identification	Clarifying concepts and generating initial ideas	Justify the relevance and feasibility of the selected problem
Requirement analysis	Searching for examples and possible functions	Formulate project requirements independently
Design and development	Code examples, debugging support, and explanation of algorithms	Adapt, test, and explain implemented solutions
Testing and revision	Error checking and alternative solution search	Verify functionality and correct project limitations
Documentation	Language editing and structuring explanations	Provide an original technical description of the project
Reflection and presentation	Preparing presentation structure	Explain decisions, limitations, and individual contribution during project defense

3.4 Assessment and Learning Activities

The intervention was designed to support three main learning objectives. These included the development of research skills, independent problem-solving, and the ability to apply theoretical knowledge to real engineering tasks. In addition, project work aimed to strengthen teamwork, professional communication, and students' ability to design and implement functional software solutions (Almulla, 2020; Rehman et al., 2024). To support the implementation of project activities, the course included a set of structured materials such as project guidelines, a timeline for project stages, and evaluation rubrics. Previous studies suggest that clearly defined expectations and transparent assessment criteria contribute significantly to the effectiveness of PBL (MacLeod & van der Veen, 2019; Pan et al., 2021; Ståhl et al., 2022).

Projects were evaluated using rubric-based assessment. The evaluation considered several aspects of project performance, including the technical quality of the solution, the completeness of implementation, the quality of documentation, and the clarity of the final presentation. In addition to presenting their projects, students were required to submit reflective reports describing their individual contributions, the challenges encountered during project development, and the strategies used to address them. Reflection is widely regarded as an important mechanism for supporting self-regulated learning and deeper cognitive engagement in project-based environments (Randazzo et al., 2021; Wu, 2024).

3.5 Data Collection and Analysis

Multiple data sources were used to evaluate the outcomes of the intervention. These included project artefacts such as software applications, source code, and technical documentation, as well as teacher evaluation rubrics and final grades. Reflective reports submitted by students were also analyzed as qualitative data sources. In addition, observations of project development and presentation sessions provided additional contextual information. Thus, the analysis did not rely only on self-reported survey data; students' perceptions were interpreted together with project artefacts, technical documentation, reflective reports, teacher evaluation rubrics, final presentations, and observations of the project process.

After the completion of the projects, students were invited to complete a short survey designed to capture their perceptions of the learning experience. The survey included questions related to motivation, perceived competence development, teamwork, and overall satisfaction. These indicators are commonly used in studies evaluating PBL environments (Santhosh et al., 2023; Randazzo et al., 2021; Rehman et al., 2024). Qualitative data from reflective reports were analyzed using an inductive thematic coding approach. The reports were reviewed multiple times in order to identify recurring themes related to autonomy, competence development, collaboration, motivation, and challenges encountered during project implementation. Thematic analysis is widely used in educational research for interpreting narrative and reflective data (Hussein, 2021; Li et al., 2022).

Survey responses were analyzed using descriptive statistics because the study did not include a control group, pre-intervention measurement, or experimental manipulation of AI use. Therefore, inferential statistics were not used to claim causal effects. Combining qualitative thematic analysis with descriptive quantitative data was consistent with the purpose of this study, which was to describe perceived outcomes and PBL experiences rather than to measure causal change. Students were informed about project requirements, evaluation criteria, and the research purpose in advance through course materials and methodological guidelines. All data were treated confidentially and used exclusively for research and educational improvement purposes.

4. Results and Findings

The implementation of the PBL enabled Master's students to engage in learning activities that closely resembled real professional practice. Throughout the intervention, students completed the entire development cycle of a project, beginning with the identification of a problem and clarification of requirements, and continuing through planning, implementation, testing, documentation, and final presentation of results.

4.1 Team-Based and Individual Project Work

During the study period, Master's students at Al-Farabi Kazakh National University completed 26 projects in total, including team-based projects developed by small groups and individual projects completed independently by students. These projects covered a wide range of technological areas. The developed solutions included mobile and web applications, generative AI tools, computer vision systems, data visualization platforms, and digital solutions designed to support business processes. A total of 10 team-based projects were implemented. Each project was carried out by groups of four to five master's students who independently organized their work, distributed responsibilities, and coordinated the development process. The themes of the projects covered a broad spectrum of technological domains, including mobile development, web systems, AI applications, and computer vision solutions. Several projects were also oriented toward solving real-world problems, which increased students' engagement and responsibility for the outcomes of their work.

Table 2 presents the team-based projects developed by Master's students during the period from 2023 to 2025.

Table 2: Team-Based Projects Developed by Master's Students (2023–2025)

Project title	Area / domain
Development of the mobile application AlaMap	Mobile development / Smart services
Mobile Application Development for iOS Operating System	Mobile development
Programming Web Courses for Newbies	Educational technologies
An application that predicts the onset of ischemic heart disease	Healthcare / Predictive analytics
"Robo eyes" website for object recognition	Computer vision
Website for Kazakh Latin alphabet conversion	Language technologies
Development of the "Almaty Media" application	Media technologies
Mobile solution for small and medium business	Business digitalization
Application for video file recognition	AI / Video analytics
Facial recognition application using neural networks	Deep learning / Biometrics

As shown in Table 2, the team projects combined software engineering tasks with applied domains such as healthcare, linguistics, media, business digitalization, artificial intelligence, and computer vision. Alongside the team projects, 16 individual projects were completed. These projects generally focused on solving more narrowly defined technical or applied problems and required students to independently analyze the problem, select appropriate tools, and implement the final solution. The individual projects addressed topics such as enterprise digitization, recommendation systems, computer vision applications, data analytics, and scientific modelling tasks.

Table 3 lists the individual projects developed during the intervention period.

Table 3: Individual Projects Developed by Master's Students (2023–2025)

Project title	Area / domain
Digital application: "Rating model for enterprise employees"	Business analytics / HR tech
Web application for enterprise digitalization	Enterprise IT
Mobile application for an applied task	Mobile development
Modeling of thermal processing of honeycombs	Engineering modeling
Data visualization system	Data analytics
Interface development for evaluating psychological factors of employees	UX/UI / HR tech
Web application "Programming learning"	Educational technologies
Web application for message exchange	Web systems
Project "Split the bill"	FinTech / Mobile services
Recommendation system based on data analytics	Data science
Application using computer vision technologies	Computer vision
Bot development for enterprise employee ranking	Automation / HR analytics
Object recognition using deep learning (cars, electronic gates)	Deep learning
Heat transfer modeling using high-performance computing in a 2D channel	Scientific computing
Development of a numerical algorithm for solving heat conductivity problems	Numerical methods
Modelling bacterial colony growth based on PINN	AI modelling / Scientific computing

As shown in Table 3, the individual projects focused on applied software development, data analytics, computer vision, AI, and scientific modelling.

4.2 Distribution of Projects by Application Areas

To obtain a clearer overview of the focus areas of the developed projects, they were grouped according to their primary application domains.

Table 4 presents the distribution of the projects across the major technological domains.

Table 4: Distribution of Projects by Domain

Domain	Number of projects	Examples
Mobile and web development	10	AlaMap, iOS app, messaging web app
Artificial intelligence / computer vision	7	facial recognition, object recognition, video recognition
Business and enterprise digitalization	4	HR rating model, enterprise digitalization, SME mobile solution
Scientific modelling and computational simulation	5	heat transfer modelling, PINN bacterial colony

Most projects were concentrated on mobile and web development, followed by AI, computer vision, and scientific modelling.

4.3 Thematic Analysis of Reflective Reports

To better understand students' learning experiences, reflective reports written after the completion of the projects were analyzed using thematic coding.

The main themes identified in the reflective reports are summarized in Table 5.

Table 5: Key Themes Identified Through Thematic Coding of Reflective Reports

Theme	Description of student reflections	Frequency (approx.)	Example student statements (translated)
Independent learning and autonomy	Students emphasized the need to search independently for information, select tools, and make informed decisions	High	"I realized that I must find solutions myself, because the teacher does not give ready answers."
Applied professional relevance	Projects were perceived as valuable due to real business/industry relevance	High	"The topic is useful for real companies, and it helped me understand professional requirements."
Motivation and engagement	Students described increased interest and intrinsic motivation due to project ownership	Medium–High	"It was more motivating than ordinary assignments because the project belonged to our team."
Teamwork and collaboration	Reflections highlighted coordination, leadership, communication, and role distribution	Medium–High	"Working in a team taught us how to divide responsibilities and communicate effectively."
Development of research skills	Students reported problem analysis,	Medium	"We had to analyze the problem deeply,

	requirement definition, testing, and evidence-based decisions		compare solutions, and justify why we chose this approach.”
Challenges of time management	Students noted difficulties meeting deadlines and balancing project tasks with coursework	Medium	“The hardest part was planning time, because the project required continuous work.”
Technical difficulties and complexity	Reports described challenges related to implementation, debugging, and integration of new technologies	Medium	“We faced difficulties when integrating the neural network model and debugging errors.”
Communication and presentation skills	Students mentioned improvement in presentation and defense competence	Medium	“Project defense improved my confidence and ability to explain technical decisions.”
Reflection and self-assessment	Students described self-evaluation of contribution and professional growth	Medium	“I understood my weak points and what skills I need to improve in the future.”
AI and ready-made solution influence	Some students noted the temptation to use ready solutions but emphasized deeper learning through project work	Low–Medium	“It is easy to take an AI-generated solution, but the project forced us to understand and improve it.”

The reflective reports indicate that students associate PBL with independent problem analysis, selection of technological solutions, teamwork, professional relevance, and self-assessment. The main challenges were related to time management, team coordination, and technical complexity.

4.4 Survey Results

To complement the qualitative findings, a post-intervention survey was conducted in order to capture students’ perceptions of their experience with PBL. Out of the 83 students who participated in the intervention, 80 completed the survey, resulting in a response rate of 96.4%.

Table 6 presents the summary of students’ responses.

Table 6: Summary of Survey Responses on Perceived PBL Outcomes (N = 80)

Survey statement	Agree / Strongly agree (%)	Neutral (%)	Disagree / Strongly disagree (%)
PBL increased my motivation to learn and complete tasks	82.50	12.50	5.00
PBL helped me develop independent learning skills	87.50	10.00	2.50
PBL strengthened my ability to solve practical professional problems	90.00	7.50	2.50
Project work improved my programming and software development skills	92.50	5.00	2.50
PBL improved my teamwork and communication competence	80.00	15.00	5.00
The PBL format improved my time management and planning skills	77.50	17.50	5.00
Project defense improved my confidence in presenting technical results	85.00	12.50	2.50
PBL helped me better understand theoretical concepts through practice	88.75	8.75	2.50
The PBL format encouraged creative thinking and innovation	76.25	18.75	5.00
The project made it harder to rely only on AI-generated solutions	68.75	21.25	10.00
I would prefer more courses to include PBL	83.75	11.25	5.00

Note: Percentages are calculated based on N = 80 and rounded to the nearest 1.25%.

As shown in Table 6, the highest levels of agreement were related to improvements in programming and software development skills (92.5%), the ability to solve practical professional problems (90.0%), understanding theoretical concepts through practice (88.75%), and independent learning skills (87.5%). In addition, 83.75% of respondents stated that they would prefer more courses to include PBL. These results indicate that students perceived PBL as a useful and applicable classroom approach.

The AI-related item received a lower but still substantial level of agreement: 68.75% of respondents agreed that the PBL format made it harder to rely only on AI-generated solutions, while 21.25% were neutral and 10.0% disagreed. This result suggests that PBL may have made exclusive reliance on AI-generated outputs more difficult for many students. However, it should be interpreted as a perceived outcome rather than as statistical evidence of a causal reduction in AI reliance.

5. Discussion

5.1 PBL and the Quality of Higher Education in the AI Era

The findings suggest that PBL should be understood as part of a broader instructional design rather than as a single solution to AI-related learning challenges. In generative AI-rich environments, this design should combine clear learning goals, structured project stages, assessment criteria, and sustained feedback. The discussion is based on the main findings reported in the results section. The survey results showed that students most strongly associated PBL with improved programming and software development skills (92.5%), practical professional problem-solving (90.0%), understanding theoretical concepts through practice (88.75%), and independent learning skills (87.5%).

These findings are supported by qualitative themes from students' reflective reports, particularly independent learning, applied professional relevance, teamwork, research skills, and responsibility for technical decisions. The novelty of the PBL implementation in this study lies in its application in a generative AI-rich software engineering context, where students were required to develop functional systems, test solutions, document the process, and defend their technical decisions. The results of the present study indicate that PBL may represent a productive pedagogical response to these challenges. Within the implemented PBL format, students were required to analyze a problem, design technical solutions, implement software systems, test the results, and justify their decisions during project defense. The AI-related findings should be interpreted cautiously. In the survey, 68.75% of respondents agreed that the PBL format made it harder to rely only on AI-generated solutions.

This suggests that, for many students, passive use of AI was less sufficient because project work required them to test functionality, adapt solutions to project requirements, prepare documentation, and explain technical decisions during project defense. Thus, PBL did not eliminate AI use, but created conditions in which AI-generated outputs had to be checked, modified, and justified by students. Similar conclusions have been reported in comparative research showing that project- and problem-based learning approaches often lead to higher levels of student engagement and critical thinking than traditional lecture-based instruction (Marcinauskas et al., 2024).

In disciplines such as software engineering and computing, learning outcomes are closely connected with practical competence. Previous studies also demonstrate that PBL strengthens problem-solving abilities and applied thinking through the implementation of authentic tasks (Upadhye et al., 2022; Karan & Brown, 2022). From this perspective, the findings of the present research support the view that PBL is well aligned with the objectives of competency-based higher education, particularly in an academic environment where generative AI tools are widely available (Balakayeva & Zeinolla, 2022).

5.2 Development of Independent Thinking and Creativity

The findings also show the relevance of PBL for independent thinking and creativity. Project tasks required students to compare alternatives, revise unsuccessful solutions, and justify their design choices. These activities supported both analytical reasoning and creative problem-solving because students had to move beyond predetermined answers and develop workable solutions.

The iterative nature of project work encourages students to explore different design strategies, compare technological alternatives, and revise their decisions when initial solutions prove ineffective. Such learning conditions naturally stimulate creative thinking and experimentation. Recent studies also indicate that PBL environments increase students' confidence in addressing complex tasks and encourage innovative approaches to practical problem solving (Karan & Brown, 2022; Marcinauskas et al., 2024). Consequently, PBL can be understood as a pedagogical framework that supports both analytical reasoning and divergent thinking, which are essential competencies for modern professional environments.

5.3 Competence Formation and Professional Preparation

The implemented PBL model contributed to competence development in several interconnected areas. First, students developed research-oriented skills by formulating project problems, analyzing system requirements, comparing technological alternatives, and evaluating the effectiveness of their solutions. In this sense, the project environment functioned as a form of applied research practice.

Second, the applied orientation of the projects strengthened their professional relevance. Many project topics were connected with real-world domains such as enterprise digitization, healthcare analytics, digital services, AI and scientific modelling. This allowed students to apply theoretical knowledge in contexts close to professional software engineering practice.

Third, the combination of team and individual projects supported different dimensions of competence. Team projects strengthened collaboration, coordination of responsibilities, and shared decision-making, while individual projects required autonomy, independent planning, and personal responsibility for the final outcome.

5.4 The Role of Mentoring, Feedback, and Reflection

The findings also highlight an important transformation in the role of the teacher within PBL environments. In contemporary digital contexts, students have access to a vast amount of information and technological tools. As a result, the teacher is no longer perceived primarily as a source of knowledge but increasingly acts as a mentor who structures the learning process and supports students' academic development. The implementation of long-term projects demonstrated that structured guidance and continuous feedback are essential for successful learning outcomes. Students frequently reported difficulties related to time management, coordination within teams, and the technical complexity of some development tasks. These observations are consistent with previous studies showing that effective PBL implementation requires clear course design and active mentoring from instructors (Upadhye et al., 2022; Marcinauskas et al., 2024).

Formative assessment also played a significant role in the learning process. Intermediate checkpoints, continuous monitoring, and feedback allowed students to revise their solutions and improve their projects during development. Educational research has consistently shown that formative assessment and feedback cycles can significantly improve the quality of learning (OECD, 2008). Reflection was another important component of the implemented model. Through reflective reports, students analyzed their own contributions, evaluated the effectiveness of their decisions, and identified areas for further improvement. From the perspective of metacognitive theory, such reflective processes support deeper learning by encouraging students to monitor and regulate their own thinking (Flavell, 1987).

5.5 Implications, Limitations, and Future Research

The results of this study have several implications for higher education practice. First, PBL can serve as an effective mechanism for aligning university education with labour market demands and industry practices, particularly in technical disciplines (Balakayeva et al., 2018). Second, the findings suggest that active learning strategies such as PBL are especially important in educational environments where generative AI tools are widely available. Because project work requires students to design original solutions and justify technical decisions, it reduces passive reliance on AI-generated outputs.

At the same time, studying has several limitations. The intervention was conducted within a single institutional context, which may limit the generalizability of the findings. In addition, the study did not include a control group or pre-intervention measurement; therefore, the results cannot be interpreted as causal evidence of the effect of PBL. The survey instruments were primarily designed for descriptive purposes rather than full psychometric validation. Finally, because the qualitative analysis of reflective reports involved researcher interpretation, potential researcher bias in thematic coding cannot be fully excluded.

Future research could therefore explore the impact of PBL using larger samples and quasi-experimental designs that compare PBL with traditional teaching approaches. Another promising direction involves examining how generative AI tools can be integrated into PBL environments in ways that support, rather than replace, students' cognitive engagement. Overall, the results suggest that PBL can contribute to the development of independent thinking, creativity, and applied professional competence. In this sense, PBL may play an important role in supporting the goals of contemporary higher education in the digital and AI-driven era.

6. Conclusion

This study examined the role of PBL in supporting student autonomy, creative problem-solving, and professional competence in software engineering education in the context of increasing access to generative AI tools. Based on student projects, reflective reports, and survey responses, the findings indicate that structured project work helped students connect theoretical knowledge with practical implementation. Students reported strong perceived benefits in programming and software development skills, practical problem-solving, independent learning, and understanding theoretical concepts through practice. The project experience also encouraged students to take greater responsibility for analyzing problems, selecting appropriate technological solutions, documenting their work, and explaining the logic of their decisions.

The specific contribution of this study lies in showing that PBL can function not only as an active learning approach, but also as a structured pedagogical design in a generative AI-rich learning environment. By requiring students to develop functional software products, test solutions, prepare documentation, reflect on their contribution, and defend technical decisions, the implemented PBL model made passive reliance on ready-made AI-generated outputs less sufficient for many students. This suggests that structured PBL can create learning conditions in which AI tools are used as learning resources rather than substitutes for students' own reasoning and problem-solving.

Therefore, carefully designed PBL may help preserve student autonomy and creative problem-solving in software engineering education, provided that project stages, assessment criteria, instructor feedback, and reflection are clearly structured. The main takeaway is that the educational value of PBL in the age of generative AI depends not simply on assigning projects, but on designing project work that requires understanding, adaptation, accountability, and ownership of the final outcome.

Conflict of Interest

The authors declare no conflicts of interest.

7. Acknowledgments

The authors acknowledge the use of generative AI tools for language editing and translation during the preparation of this manuscript. These tools were used solely to improve grammar, clarity, and linguistic accuracy. All research ideas, analysis, interpretation of results, and conclusions presented in this paper are the authors' original intellectual contributions.

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