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Enhancing students' self-efficacy and creativity in computer numerical control machining through peer-assisted project-based learning

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ABSTRACT

The demand for increasingly diverse product designs and specifications in the manufacturing industry requires Computer Numerical Control (CNC) machine operators to have high technical skills and strong self-efficacy and creativity. High self-efficacy allows operators to be more confident in applying their technical skills, while creativity helps them solve problems and challenges during the production process. This study aims to improve students' self-efficacy and creativity by applying the Peer-Project Based Learning (Peer-PjBL) model, which combines aspects of project-based learning with peer-to-peer learning. The method used in this research is Classroom Action Research (PTK), which consists of two implementation cycles. Each cycle involves planning, implementation, observation, and reflection stages. The subjects of this study were 20 students who took the CNC Machining Technology course at Universitas Negeri Yogyakarta. Data were collected using a questionnaire that measured self-efficacy and student creativity indicators and then analyzed descriptively. The results showed that applying the Peer-PjBL method significantly increased students' self-efficacy and creativity in each research cycle. This improvement can be seen in students' ability to face new challenges independently, as well as their ability to generate diverse creative ideas in solving problems. This research makes an important contribution to the development of learning methods in vocational education by emphasizing the improvement of technical abilities and non-technical skills, such as self-efficacy and creativity, which are needed in the modern world of work.

INTRODUCTION

The era of industrial automation is characterized by the trend of using Computer Numerical Control (CNC) machines that dominate the manufacturing industry (Chen et al., 2022; Zeng, 2020). CNC machines have advantages such as production process efficiency, product accuracy, and producing products with complex geometries (Dai et al., 2022; Dowluru et al., 2022). The trend of using CNC machines continues to grow, along with the demand for precise and innovative products and the speed of production time (Dai et al., 2022; Huo & Poo, 2013). The utilization of CNC technology and increasing production efficiency can also provide flexibility in creating various products following changing market demands (But et al., 2021). The utilization of CNC machines in manufacturing has become a key pillar in today's industrial production and innovation strategies.

The dominant use of CNC machines in the manufacturing industry drives the need for workers who are competent in operating them. CNC machine operators are required to run the machine precisely and have skills in solving problems and creating solutions in every production process (Huo & Poo, 2013; Vinod et al., 2006; Wijarwanto & Wijanarka, 2019) . Increased automation in production activities encourages CNC machine operators to work efficiently by optimizing the production process. However, it's not just about efficiency. CNC machine operators must also be creative to adjust to the demands of increasingly diverse product designs and specifications (Wibowo et al., 2017). This creativity is not just a requirement, it's an inspiration, a call to arms to respond to any challenges in every production activity.

Technical skills possessed by CNC machine operators will become more empowered if supported by high self-efficacy. Self-efficacy is a psychological dimension related to a person's belief in their abilities (Khalique & Singh, 2019; Kodden, 2020). Workers who have high confidence in their ability to solve challenges will be proactive in dealing with work situations. This high self-confidence will open up opportunities to increase work productivity because self-efficacy is often associated with mental resilience and the capacity to deal with pressure (Konaszewski et al., 2021; Shanava & Gergauli, 2022). Self-efficacy encourages CNC machine operators to continue developing their abilities (Kodden, 2020; Venugopal et al., 2020). High self-efficacy can encourage workers to continue to learn and improve their skills as the complexity of technology continues to grow.

Vocational education as a labor provider needs to prepare its graduates to match the needs of the industry. CNC learning in higher education should not only be about improving technical skills but also be related to available job opportunities. Students may find it difficult to enter the increasingly competitive job market if they do not fully have self-efficacy and creativity. Jobs in CNC learning currently come more from lecturers/instructors. The complexity of the jobs done by students varies based on the intended Graduate Learning Outcomes (LLOs). Job complexity is minimal because lecturers pragmatically use jobsheet references as teaching media taught to students. In addition, changes in CNC jobs each year do not show significant differences. This means that the jobs done by students still rely on old jobs. Of course, the dynamics of changes in the demands of the world of work in the CNC field are increasingly complex and varied, so students need to be equipped with job variants that adjust CNC work in the present. Universities need to choose a fixed learning strategy to help students develop their creativity and self-efficacy in completing jobs derived from lectures and industry research products.

Project-based learning (PjBL) as a project-oriented learning model has begun to be widely used in vocational learning, especially CNC learning (Khamidulin, 2020). Despite its popularity, the use of project-based learning is still constrained by the consistency of its application. Lecturers' difficulties in determining the theme of the project being worked on are limited by the stock of projects collaborating with industry (Jang, 2022; Kakde, 2022). Because the practicality of using PjBL is quite difficult, many lecturers return to conventional methods, namely textbooks, dominating lectures, demonstrations, and drills. The PjBL model has potential that can be developed if it is deepened using other methods, namely peer tutoring or peer learning. Peer tutoring is a learning method that prioritizes activeness between students, with one party acting as a tutor and vice versa (Knight & Brame, 2018; Loda et al., 2020).

The Project-based Learning (PjBL) model enhances the learning experience by introducing authentic projects that reflect real-life situations in the classroom (Guo et al., 2020; Jones, 2019; Khamidulin, 2020). These projects allow students to enhance their creativity by designing practical solutions and increasing their self-efficacy by tackling real challenges (Buana & Putra, 2023; Jing et al., 2023; Pramatarova, 2021; Voronova, 2021). Meanwhile, the Peer-PjBL model, which is a combination of Peer Learning and PjBL, facilitates a more in-depth exchange of information and fosters a supportive atmosphere that increases students' confidence in using their skills (Bone et al., 2019; Jeanneau & O'Riordan, 2020; Tullis & Goldstone, 2020). Peer learning encourages student interaction and promotes collaborative learning, providing a platform to exchange ideas and engage in joint problem-solving (Duran & Miquel, 2019; Ortiz et al., 2019). The combination of peer learning and project-based learning (Peer-PjBL) methods allows students to develop their technical skills and also helps improve their self-efficacy and creativity.

Computer Numerical Control learning has often used PjBL only. Previous research has used PjBL only and has not implemented peer-PjBL (Beneroso & Robinson, 2022; Li et al., 2022; Pramanik et al., 2019). The choice of the peer-PjBl approach is based not only on the need for comprehensive technical understanding but also on the desire to increase students' confidence and creativity in responding to the changing needs of the industry. The expected goal of the classroom action research that we will conduct is to generate significant insights into the efficacy of the peer-PjBL approach in enhancing students' self-efficacy and articulateness. With this research, we will improve the scientific literature in vocational education and make a real contribution to advancing practical learning methods in vocational education, particularly in CNC practical learning. This research advises educational practitioners to improve learning approaches that enable students to become leaders in an increasingly complex and innovative industrial world.

METHOD

In this study, the classroom action research approach was applied to enhance students' self-efficacy and creativity in CNC practice using the Peer-PjBL (Peer-Project Based Learning) model. The classroom action research method involves iterative cycles, allowing researchers to gradually refine the learning approach based on findings from each cycle (Kemmis et al., 2014). This research procedure was carried out in 2 cycles, each consisting of preparation, implementation, observation, and reflection (Arikunto et al., 2023). After the reflection stage in the first cycle, the lesson plan is adjusted and revised for implementation in the next cycle. This approach ensures that the development of the project-based learning model is carried out systematically and continuously improved based on empirical data.

This classroom action research approach enables continuous improvement in the learning model, ensuring a more significant impact on enhancing students' self-efficacy and creativity in CNC practice. The research cycle used in this study is presented in Figure 1, which adapts the classroom action research model from Kemmis and McTaggart (Denzin & Lincoln, 2008).

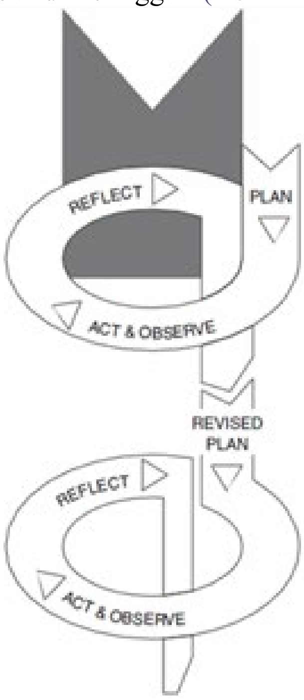

Figure 1. Kemmis and Mc Taggart Cycle (Denzin & Lincoln, 2008)

This research was conducted in the mechanical engineering education study program at Universitas Negeri Yogyakarta, focusing on improving students' self-efficacy and creativity in the CNC Machining Technology course. The subjects of this study were 20 students who actively participated in the project-based learning approach implemented in this research. To measure self-efficacy and creativity, a questionnaire instrument was used, referring to specific indicators that had been structured beforehand. Self-efficacy indicators include self-assessment, confidence in decision-making, and willingness to face challenges, as detailed in Table 1. Meanwhile, creativity indicators involve aspects of flexibility, originality, elaboration, and fluency in thinking and problem-solving, as shown in Table 2.

Additionally, the data analysis technique used in this study is descriptive analysis, which aims to describe the trends and patterns emerging from students' responses to the given instruments. This analysis allows researchers to identify the extent to which the project-based learning model contributes to enhancing students' confidence and creativity in CNC machining practices. With this approach, the study does not only evaluate learning outcomes quantitatively but also provides qualitative insights into how students face challenges and complete tasks assigned in this course. The findings of this study are expected to provide recommendations for the development of a more innovative curriculum in technical education, particularly in implementing learning methods that foster improvements in students' cognitive and affective skills.

Table 1. Self-efficacy indicators

Indicators	Sub Indicators
Self-assessment	Assessment of employability
	Self-assessment of excellence
	Assessment of achievements
Self-assertiveness	Assertiveness in task completion
	Decisiveness of decision-making
	Firmness of stance
Willingness	Willingness to accept challenges
	Willingness to accept change
	Willingness to bear risk

Table 2. Indicators of Creativity

Indicators	Sub Indicators
Flexibility	Generate a variety of ideas, answers, or questions
	Looking at a problem from different angles
	Seeking many alternatives or different directions
Originality	Creating new and unique jobs
	Thinking of unconventional ways to express yourself
	Have the willpower to complete the program
Elaboration	Responds to questions passionately, actively, and eagerly in completing tasks
	Courageous to accept or carry out challenging tasks
	Happy to find practical ways or methods of learning
	Critical in checking work
	Aggressive questioning
Fluency	Generates many ideas, answers, and solutions to problems or questions
	Independent in learning

RESULTS AND DISCUSSION

Results

The results presented in Figure 2 demonstrate a gradual improvement in students' self-efficacy throughout the research cycles. Before implementing the Peer-Project Based Learning (Peer-PjBL) model, the students' average self-efficacy level was relatively low, recorded at 35% in the pre-cycle phase. This stark starting point, indicating that before the intervention, students exhibited low confidence, hesitation in decision-making, and reluctance to take on challenges in CNC machining practices, sets the stage for the significant progress that follows.

Following implementing the first cycle of Peer-PjBL learning, a significant increase in self-efficacy was observed, reaching 67%. This notable improvement suggests that the collaborative nature of problem-solving and peer-based interactions not only helped students become more engaged, confident, and proactive in addressing the challenges posed by CNC machining tasks, but also instilled a sense of ownership and initiative in their learning process. The first cycle specifically focused on Lathe work material, where students worked in groups to generate and solve machining-related problems, reinforcing their ability to assess their competencies, make independent decisions, and apply their skills effectively.

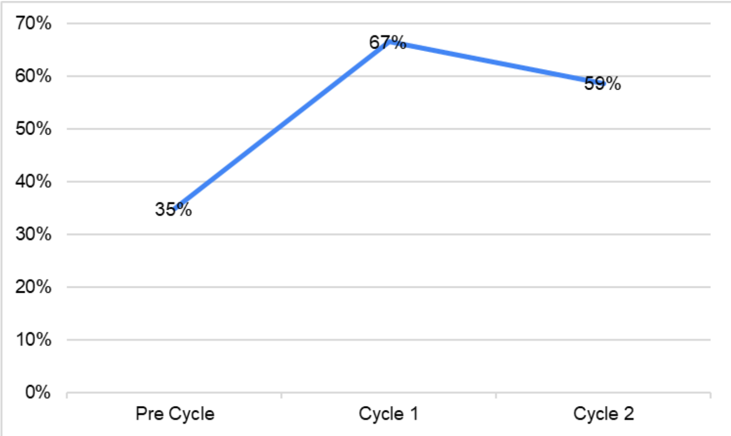

Figure 2. Number of Students Who Completed the Self-Efficacy Indicator

In the second cycle, however, a slight decline in self-efficacy was recorded, dropping to 59%. While this still represents an overall improvement compared to the pre-cycle phase, the decrease suggests potential challenges encountered in the second cycle, which focused on Fracture work material. The complexity of the tasks, the cognitive demands of the material, or possible group dynamics influenced the slight reduction in confidence levels. This highlights the need for consistently adjusting instructional strategies to improve self-efficacy across different CNC topics.

These findings indicate that applying the Peer-PjBL model positively impacts students' self-efficacy by fostering collaboration, problem-solving, and independent learning skills. However, to ensure sustainable growth in self-efficacy, it is crucial that future implementations prioritize adaptive strategies. These strategies should cater to varying levels of task complexity, providing additional scaffolding for more challenging topics, and should be a key focus of future research and practice in the field.

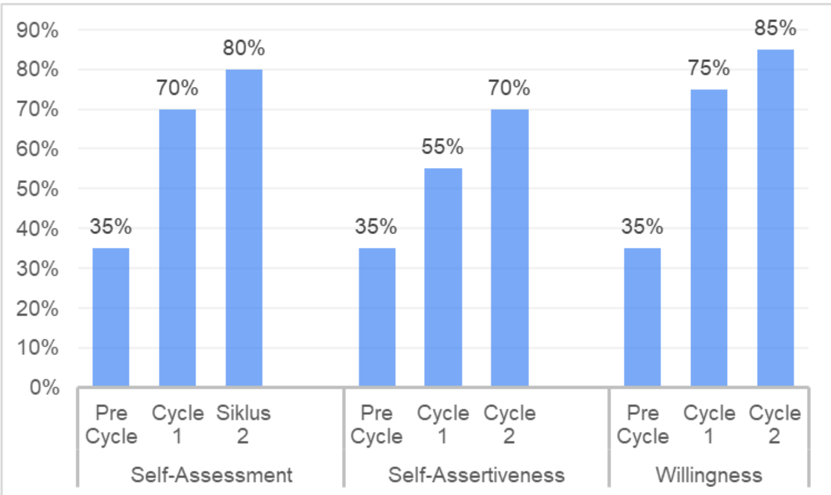

Figure 3. Classical Completeness of Students on Self-Efficacy Indicators

Figure 3 illustrates the development of students' self-efficacy indicators through the Peer-Project Based Learning (Peer-PjBL) model in each research cycle. The self-assessment indicator in the pre-cycle stage shows that only 35% of students could complete tasks confidently. However, after implementing Peer-PjBL, there was a significant increase in Cycle 1 (70%), followed by further improvement in Cycle 2 (80%), indicating that this method effectively enhances students' ability to evaluate themselves.

Next, the Self-Assertiveness indicator in the pre-cycle stage also exhibited a similar percentage (35%), indicating that students initially lacked confidence in completing tasks and making decisions. However, with the introduction of project-based learning and the crucial element of peer support, a substantial increase was observed in Cycle 1 (55%), which further improved in Cycle 2 (70%). This underscores the significant role of active interaction among students in developing their assertiveness and decisiveness in taking action.

Meanwhile, the Willingness indicator also experienced a significant improvement. In the pre-cycle stage, only 35% of students demonstrated readiness to accept challenges and adapt to changes in the learning process. After implementing Peer-PjBL, this value increased to 75% in Cycle 1 and reached 85% in Cycle 2. This indicates that this learning method not only fosters students' motivation and preparedness to face academic challenges, but also empowers them to do so more independently and confidently.

Overall, this graph demonstrates that the Peer-PjBL model effectively improves students' self-efficacy, particularly in self-assessment, self-assertiveness, and willingness—which are not just academic skills, but also essential for future professionals in technology-driven industries. This underscores the relevance of our research to the field of education and its potential impact on the future workforce.

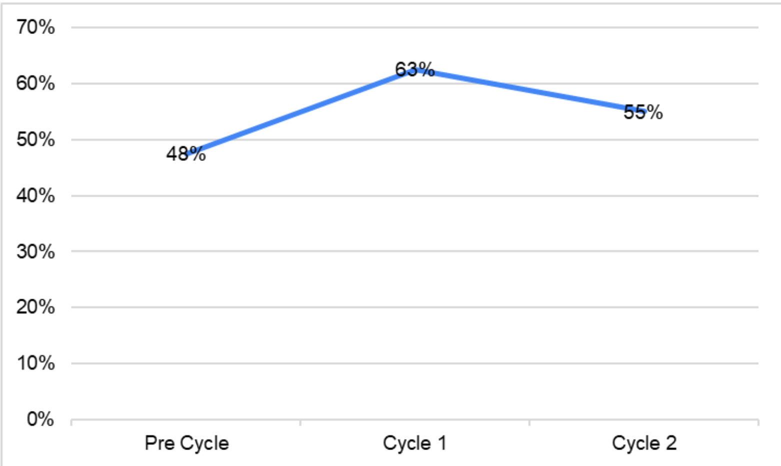

Figure 4. The Number of Students Who Completed the Creativity Indicator

Figure 4 presents the average indicator of student creativity across different learning cycles using the Peer-Project Based Learning (Peer-PjBL) approach. The data was collected through structured group activities, where students were tasked with developing problem scenarios for their peers to solve. These activities involved hands-on tasks, such as designing and fabricating specific components using CNC machines, and required students to collaborate and share their knowledge and skills. The first cycle focused on Lathe work material, while the second cycle emphasized Milling (Frais) work material, allowing students to explore different aspects of CNC machining.

From the graph, it is clear that students' creativity showed a significant improvement from the pre-cycle stage to Cycle 1. Initially, only 48% of students demonstrated strong creative problem-solving abilities. However, after implementing Peer-PjBL in Cycle 1, this percentage increased substantially to 63%. This significant leap underscores the value of hands-on learning activities and, more importantly, peer collaboration in enhancing their ability to generate innovative solutions.

In Cycle 2, the creativity indicator slightly decreased to 55%. This decline suggests that while students maintained a higher level of creativity than in the pre-cycle stage, they may have faced more complex challenges in the second cycle, particularly with Frais work material, which requires higher precision and problem-solving skills. To sustain their creative momentum, students may need additional guidance or exposure to varied CNC machining tasks, such as more hands-on practice with different types of CNC machines or real-world problem-solving scenarios. This will not only help them maintain their creativity but also prepare them for the diverse challenges they may encounter in their future careers.

Overall, the results in Figure 4 underscore the effectiveness of the Peer-PjBL method in enhancing student creativity, particularly in problem formulation, idea generation, and innovative thinking. The observed fluctuation between cycles serves as a stark reminder of the necessity for continuous refinement in instructional strategies. This is crucial to sustain student engagement and creative performance throughout the learning process.

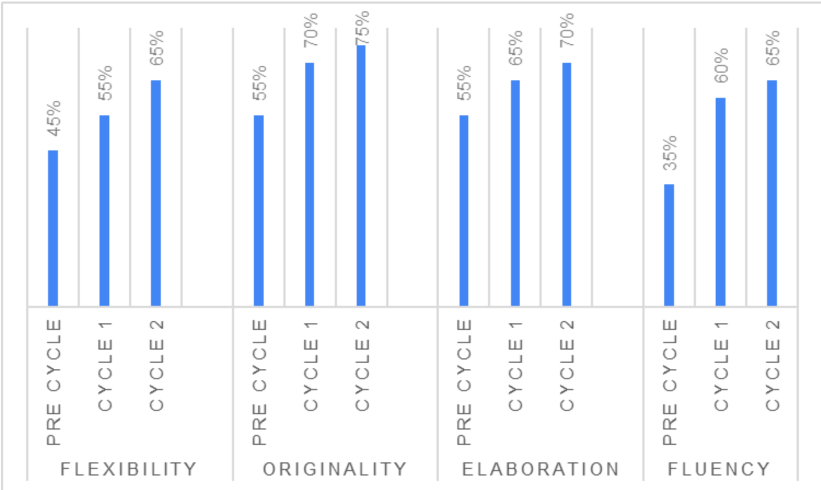

Figure 5. Classical Completeness of Students on Creativity Indicators

Figure 5, a visual representation of the range of student creativity indicator scores, serves as a compelling testament to the transformative power of Peer-Project Based Learning (Peer-PjBL). The creativity indicators, Flexibility, Originality, Elaboration, and Fluency, measured in this study, show a remarkable and consistent improvement from the pre-cycle stage to Cycle 1 and Cycle 2. This not only validates the effectiveness of Peer-PjBL but also underscores its profound impact on enhancing student creativity.

Consider the Flexibility indicator, which signifies the ability to generate diverse ideas and approach problems from different perspectives. At the pre-cycle stage, 45% of students were categorized as complete. However, after the implementation of Cycle 1 and Cycle 2, this percentage increased to 55% and 65%, respectively. This significant progress indicates that students are becoming more adaptable and open to multiple solutions, a promising result of Peer-PjBL.

For the Originality indicator, which gauges the ability to produce unique and unconventional ideas, the results are particularly striking. At the pre-cycle stage, 55% of students demonstrated this skill. However, as the cycles progressed, this number rose to 70% in Cycle 1 and further to 75% in Cycle 2. This steady increase is a clear indication of students' progressive development of more innovative approaches to problem-solving, a direct result of the effective implementation of Peer-PjBL.

When it comes to Elaboration, which assesses students' ability to expand on ideas, critically analyze problems, and provide detailed explanations, the results are equally promising. At the pre-cycle stage, 55% of students completed this indicator. As the cycles progressed, this number showed a steady improvement, reaching 65% in Cycle 1 and 70% in Cycle 2. This steady improvement is a clear testament to the effectiveness of Peer-PjBL in enhancing students' ability to develop well-structured and comprehensive solutions.

Lastly, let's consider the Fluency indicator, which reflects students' ability to generate numerous ideas or solutions efficiently. At the pre-cycle stage, 35% of students completed this indicator. However, after Cycle 1, this figure saw a notable increase to 60%. In Cycle 2, it further improved to 65%. This improvement demonstrates that students are becoming more proficient in articulating multiple solutions and expressing their ideas effectively, a clear sign of the impact of Peer-PjBL.

The results shown in Figure 5 confirm that Peer-PjBL positively impacts all aspects of student creativity, with each indicator showing a steady increase across both cycles. While some variations exist between indicators, the overall trend suggests that integrating collaborative project-based learning strategies encourages students to think more flexibly, generate original ideas, elaborate their thoughts, and articulate solutions fluently. This improvement highlights the importance of incorporating active and peer-based learning approaches to enhance student creativity and problem-solving abilities in CNC education. These findings set the stage for further discussion on the implications of Peer-PjBL in vocational education and practical applications in industrial training environments.

Discussion

Applying the Peer-project-based Learning (Peer-pjBL) model in the CNC Machining Technology course can increase student self-efficacy and creativity. Based on the results of the study, it was obtained that the average self-efficacy had a significant increase from the pre-cycle stage to cycle 2. In the creativity indicator, there was a significant increase from the pre-cycle stage to cycle 2. The Peer-PjBL model can improve students' self-efficacy and creativity in CNC Machining Technology (Kim, 2021). The steps of Peer-PjBL are creating teams, providing challenges, developing project plans, reviewing project suitability, creating projects, team monitoring, presenting projects, and peer assessment.

Learners create groups of several students to interact and coordinate to solve problems. Each group creates an inter-group project that must be done in learning. The challenges given to other groups are in the form of clues adjusted to the learning outcomes. Project planning serves to prepare the project based on the challenges given by other teams. They review the suitability of the project and review the project plan that has been made based on the challenges of other teams. The instructor validates whether or not the project can be done based on the facilities available.

Project creation implements and tests the challenge project the other group gave based on the fixation of the job sheet review. Team monitoring to review the product that has been created. Instructors and teams give each other feedback. Project presentation stage is used as a platform for each team to present the product that has been made. Other teams will listen and respond. Product assessment is done through the peer assessment method, where other groups will assess the products produced by the team based on predefined criteria and guidelines. This assessment can be a lesson learned for assessors and assesses to provide practical products that are mutually beneficial both theoretically and applicatively.

The results of this study demonstrate the remarkable growth of students' self-efficacy and creativity. Students who have developed self-efficacy show a willingness to accept challenges and solve new problems, displaying a deep interest and curiosity in the tasks at hand. They exhibit patience and independence in completing complex tasks, showing a preference for maintaining their autonomy rather than being influenced by other groups. On the creativity indicator, they display a high level of self-confidence and independence. Moreover, students show an extraordinary ability to overcome problems, demonstrating a high level of curiosity and patience. A student with such creativity is open to new experiences, willing to take risks, and, most importantly, has confidence in their abilities.

This study found that the Peer-PjBL learning method effectively improves teamwork competencies. Among the teamwork competencies, it was found effective in creating challenges for other groups and completing challenges from other groups. Teamwork is favored over individual competence due to the tendency to solve team problems or tasks. The demand for improving the quality of education in universities is increasing along with changes in the social environment. Conventional education methods that focus on delivering knowledge are transforming into learner-centered education that can recognize and solve practical problems. This study's results align with previous studies, which state that it is more effective to solve problems a group or organization faces based on ideas shared between members than relying on individual competence (Kim, 2021). When each group strives to solve problems as a team, it becomes highly meaningful for universities to pursue efficient learning activities.

The peer-PjBL learning method can increase self-efficacy and creativity by solving problems openly and confidently when facing new ones (Dunlap, 2005; Napitupulu, 2022). By integrating the Peer-PjBL learning method, students develop their academic skills and hone their social skills through interaction with teammates. The collaborative learning process in Peer-PjBL emphasizes the achievement of learning objectives and stimulates personal growth through peer reflection and feedback. This collaboration teaches students to approach challenges positively, build confidence, and explore creative solutions. As such, this method focuses on knowledge transfer and seeks to fully develop students' potential, creating a dynamic and empowering learning environment.

Despite its effectiveness, this study has several limitations. Firstly, the research was conducted within a single educational institution, limiting the generalizability of the findings to broader contexts. Future studies should involve multiple institutions to enhance comparative analysis and validity. Secondly, while the study demonstrated significant improvements in self-efficacy and creativity, it did not assess long-term retention of these skills. Future research should explore longitudinal impacts, particularly how students apply these competencies in industrial or professional settings. Additionally, resource constraints and technical limitations in CNC training environments could affect the scalability of the Peer-PjBL model. Addressing these challenges through technological advancements and expanded institutional support will be crucial for wider adoption.

The implications of this study are not limited to the field of education but also extend to industry. For educators, these findings underscore the importance of integrating peer-based active learning strategies to bridge the gap between theoretical knowledge and practical application. The Peer-PjBL model, with its focus on hands-on skills and teamwork, is particularly relevant for technical and vocational education, preparing students for the demands of the workforce. Furthermore, this study contributes to pedagogical advancements in CNC training by demonstrating how structured collaborative learning approaches can enhance student competencies in a practical, real-world context.

Looking ahead, it is crucial that future research explores alternative instructional technologies, such as virtual reality (VR) or augmented reality (AR) simulations, to complement hands-on Peer-PjBL learning. Additionally, expanding the cross-disciplinary applications of this model in fields such as robotics, automation, and smart manufacturing may further enhance its effectiveness. This research underscores the importance of interactive, peer-driven learning strategies in shaping the next generation of highly skilled and innovative professionals in CNC machining and other technical disciplines, and it is imperative that we continue to explore and refine these strategies.

CONCLUSION

The results of this study indicate that applying the Peer-Project-Based Learning (Peer-PjBL) method in CNC Machining Technology courses effectively enhances students' self-efficacy and creativity. This finding highlights that integrating Peer-PjBL not only improves technical competencies but also fosters essential non-technical skills, such as problem-solving, teamwork, and confidence in tackling new challenges. Furthermore, the study underscores the potential of this learning model to be adapted and implemented across other vocational education courses, offering a structured yet flexible approach to competency-based learning. Additionally, this research opens avenues for further exploration of how non-technical aspects, such as collaboration, critical thinking, and adaptability, can enrich practical learning experiences and contribute to curriculum development. By emphasizing both technical proficiency and soft skills, the Peer-PjBL model aligns with the evolving demands of the modern workforce, ensuring that students are better prepared to navigate real-world challenges in their respective fields. Future research can focus on refining this approach, expanding its application across different educational settings, and assessing its long-term impact on student learning outcomes and industry readiness.

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