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The Implementation of Project Based Learning Model in CAD/CAM Instruction to Improve Learning Outcomes of Mechanical Engineering Students

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ABSTRACT

This study aims to analyze the effectiveness of implementing the Project Based Learning (PjBL) model in the CAD/CAM course to improve the learning outcomes of Mechanical Engineering students at Universitas Tomakaka. Using a quasi-experimental method with a pretest-posttest control group design, the study involved 60 fourth-semester students divided equally into an experimental group taught with PjBL and a control group taught using conventional methods. Data were collected through cognitive tests, project assessments, and affective rubrics, then analyzed using normality and homogeneity tests, independent t-tests, and N-Gain scores. The findings showed that the experimental group experienced significant improvement in cognitive learning outcomes, with higher posttest scores and moderate to high N-Gain values, compared to the control group, which demonstrated only low improvement. Psychomotor outcomes also revealed a strong positive effect, with the PjBL group outperforming the control group in 3D modeling accuracy, design quality, and software utilization. Furthermore, affective outcomes highlighted that the experimental group exhibited greater teamwork, communication, and participation, supported by significant statistical differences. These results confirm that PjBL is an effective learning model that enhances not only cognitive and technical competencies but also essential soft skills required by the engineering profession. The integration of PjBL in CAD/CAM courses provides a holistic learning experience that prepares students to face the challenges of Industry 4.0. This study recommends broader implementation of PjBL in technical education, supported by adequate facilities and collaboration with industry to ensure the relevance and sustainability of project-based curricula.

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INTRODUCTION

Higher education in the field of engineering, particularly mechanical engineering, is required to continuously innovate in teaching methods in line with the development of industrial technology. One of the main challenges in learning is how to create a learning experience that can develop technical skills while also enhancing graduates' competitiveness in the workforce. The CAD/CAM (Computer-Aided Design and Computer-Aided Manufacturing) course is an essential part of the mechanical engineering curriculum because it provides practical abilities in digital design and manufacturing. However, traditional teaching approaches, which are largely lecture-based and demonstrative, are often insufficient in developing students' conceptual understanding and practical skills (Tjalla, 2020).The *Project Based Learning* (PjBL) model offers a strategic solution to improving the quality of practice-oriented engineering education. This approach emphasizes student involvement in completing real-world projects that are relevant to the industry, allowing students not only to understand concepts but also to apply them directly. A study by Hanif et al. (2019) revealed that the implementation of PjBL in engineering learning significantly improved students' creativity, critical thinking skills, and learning outcomes. This demonstrates that PjBL has great potential to be applied in CAD/CAM learning, which requires a combination of theory and practice.

The implementation of PjBL also aligns with the constructivist approach in education, where students are positioned as active subjects in the learning process. Students are expected to build their own understanding through exploration, collaboration, and reflection during project work. In the context of mechanical engineering learning, such projects may include component design, digital modeling, and even simulation of manufacturing processes. According to Sugiyanto and Hidayah (2021), this approach not only improves technical skills but also strengthens soft skills such as communication, leadership, and teamwork, which are highly demanded in the modern workforce.Universitas Tomakaka, as one of the higher education institutions offering a Mechanical Engineering Study Program, faces challenges in enhancing the quality of education that is responsive to the development of industrial technology. Initial observations indicate that CAD/CAM learning still tends to focus on delivering material and standard practicums without linking them to real-world projects. This has led to low student engagement and suboptimal mastery of competencies required by industry. Therefore, innovation in teaching approaches is necessary through the integration of the PjBL model into the CAD/CAM course to create a more meaningful and applicable learning process (Nasution & Siregar, 2022).

Several previous studies have proven the effectiveness of the Project Based Learning (PjBL) model in the context of engineering education. For instance, research by Rochman and Yuliana (2020) showed that students who learned through a project-based approach tended to have a higher level of understanding and skills compared to those who studied using conventional methods. Furthermore, the study conducted by Fitriani and Maulidiyah (2021) also found that integrating PjBL into technology-based learning increased students' learning enthusiasm and improved their final exam results. Therefore, it is important to evaluate how the implementation of PjBL in a local context, such as at Universitas Tomakaka, can influence the learning outcomes of mechanical engineering students, particularly in mastering CAD/CAM.The implementation of Project Based Learning (PjBL) in CAD/CAM learning can also enhance students' higher-order thinking skills. This is in line with the research conducted by Kurniawan and Lestari (2020), which indicated that PjBL encouraged students to analyze, evaluate, and create innovative solutions to address technical problems. In the CAD/CAM context, students are challenged to produce designs that are not only technically accurate but also meet industrial standards. Thus, PjBL strengthens problem-solving abilities, which are essential competencies for mechanical engineering graduates.

In addition, integrating PjBL into CAD/CAM courses can significantly increase students' learning motivation. According to Abdullah and Pratama (2021), students involved in real projects tend to have higher intrinsic motivation because they perceive their learning as relevant to industry needs. This motivation not only impacts academic achievement but also encourages active participation in group discussions and project presentations. Such conditions are crucial for producing graduates who are work-ready and competitive on a global scale.The effectiveness of PjBL in enhancing collaborative skills should also not be overlooked. Setyawan and Wahyuni (2022) emphasized that the application of PjBL in technology-based courses provides ample opportunities for students to work in teams, share tasks, and complete projects according to schedule. In CAD/CAM learning at Universitas Tomakaka, this is particularly important as digital design and manufacturing often require cross-disciplinary collaboration, from planning to product implementation. Such collaboration prepares students to face the dynamics of teamwork in real industrial environments.

Furthermore, the implementation of PjBL contributes to the development of students' digital skills. A study by Rahmatullah and Indrawan (2023) found that engineering students engaged in CAD/CAM projects based on PjBL showed significant improvements in 3D modeling skills and the use of manufacturing software. This improvement is not only relevant to academic achievements but also supports the demands of an industry increasingly reliant on digital technology. With mastery of such technologies, graduates are expected to be more competitive in facing the challenges of the Industrial Revolution 4.0. Finally, in the context of

Universitas Tomakaka, the implementation of PjBL is expected to have a direct impact on the quality of graduates produced. Recent research by Malik and Sari (2024) indicated that higher education institutions applying PjBL in their engineering curricula experienced a significant increase in the percentage of graduates absorbed into the workforce within a short time after graduation. Thus, integrating PjBL into CAD/CAM learning is not only an academic solution but also an essential strategy to enhance the competitiveness of Universitas Tomakaka at both regional and national levels.

The application of PjBL also contributes to improving students' ability to integrate theory and practice. According to Arifin and Nurdin (2019), students involved in project-based learning demonstrated a deeper understanding of technical concepts because they directly applied them in real contexts. In the CAD/CAM course, this allows students not only to understand design and manufacturing theory but also to master the stages of its implementation. Consequently, learning becomes more meaningful as it is directly linked to workplace demands. On the other hand, the successful implementation of PjBL in CAD/CAM learning is also determined by the readiness of lecturers to design and manage projects. As explained by Yusof and Rahman (2020), lecturers play an important role as facilitators who guide students toward achieving learning objectives without diminishing their independence in completing projects. This requires skills in designing challenging projects, preparing clear assessment indicators, and providing constructive feedback. Without full lecturer support, the implementation of PjBL may be less effective.

In addition to the role of lecturers, support in terms of facilities and technology is also a crucial factor. A study by Pramudita and Sari (2021) emphasized that the availability of adequate software and hardware in CAD/CAM laboratories greatly determines the success of project-based learning. Universitas Tomakaka must ensure that students have access to modern CAD/CAM equipment in order to complete projects that meet industrial standards. If the facilities are sufficient, the learning process will not only be more effective but also more engaging and relevant for students. Furthermore, evaluating the effectiveness of PjBL implementation in CAD/CAM can provide a concrete picture of its contribution to students' learning outcomes. According to Wibowo and Santosa (2022), project-based assessment offers more comprehensive information on students' abilities, covering cognitive, affective, and psychomotor aspects. Such thorough evaluation can be used as a basis for curriculum development and the improvement of teaching methods at Universitas Tomakaka, ensuring continuous quality enhancement in education.

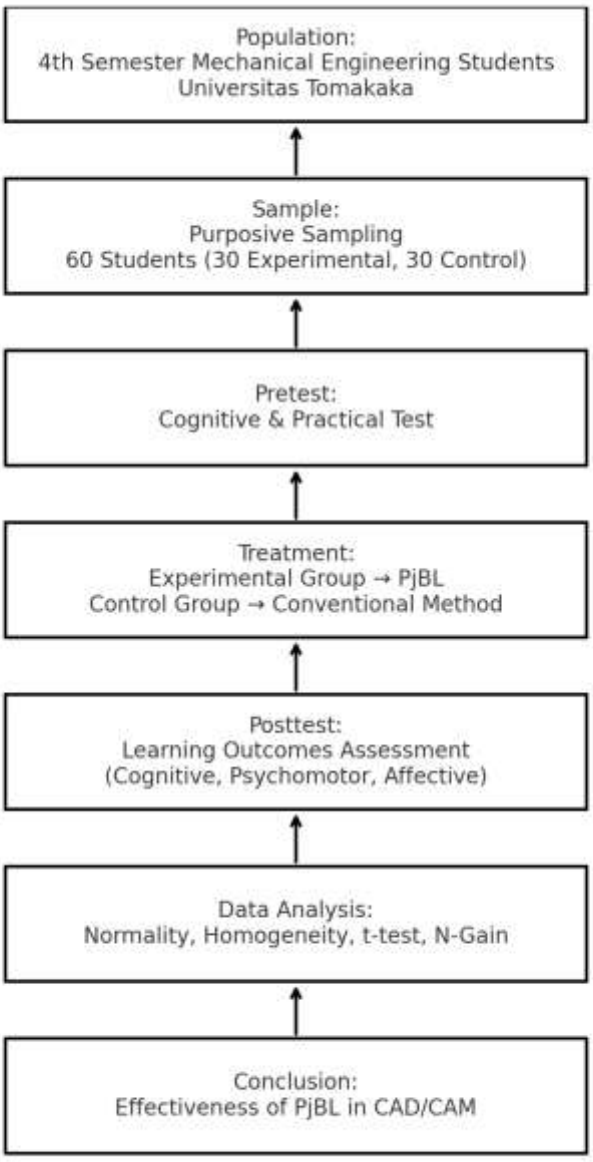
METHODOLOGY

This study employed a quantitative approach with a quasi-experimental method to examine the effect of implementing *Project Based Learning* (PjBL) on students' learning outcomes in the CAD/CAM course. The research design used was a pretest-posttest control group design, consisting of two groups: an experimental group that received learning through the PjBL model and a control group that received conventional instruction. This design was chosen to objectively measure changes in students' learning outcomes after the treatment was applied (Creswell & Guetterman, 2021).

The population of the study comprised all fourth-semester students of the Mechanical Engineering Study Program at Universitas Tomakaka who enrolled in the CAD/CAM course during the 2025/2026 academic year. The sample was determined using a purposive sampling technique, involving 60 students who were equally divided into the experimental and control groups. The selection considered the students' academic equivalence based on prerequisite course grades and pretest results (Sugiyono, 2019). Thus, the findings are expected to represent the actual conditions in the CAD/CAM classroom.

The research instruments included a learning outcome test consisting of multiple-choice and essay questions to measure cognitive aspects, as well as a project assessment rubric to measure psychomotor and affective aspects. The validity of the instrument was tested through content validity involving three CAD/CAM expert lecturers, while reliability was assessed using Cronbach's Alpha coefficient, with a minimum score of 0.70 considered a good reliability indicator (Fraenkel et al., 2020). In addition to the test, observations and documentation of project implementation were conducted to strengthen the research data.

Data analysis included normality and homogeneity tests as prerequisites for hypothesis testing. Furthermore, an independent t-test was conducted to determine the difference in learning outcomes between the experimental and control groups. Additionally, the N-Gain Score was calculated to identify the improvement in learning outcomes for each group. Both descriptive and inferential interpretations were applied to provide a comprehensive overview of the effectiveness of PjBL in CAD/CAM learning at Universitas Tomakaka. Through this method, the study aimed to provide strong empirical evidence regarding the contribution of PjBL to enhancing the competencies of mechanical engineering students.



Picture 1. Flowchart Research

This research flowchart illustrates the sequence of the quasi-experimental method applied in the study of implementing *Project Based Learning* (PjBL) in CAD/CAM learning at Universitas Tomakaka. The research began by defining the population, namely all fourth-semester Mechanical Engineering students enrolled in the CAD/CAM course. From this population, a sample of 60 students was selected using a purposive sampling technique and divided into two groups: an experimental group that received PjBL-based learning and a control group that followed conventional methods.

Prior to the treatment, both groups undertook a pretest to assess their initial cognitive and practical skills. The experimental group was then exposed to PjBL, while the control group continued with traditional learning methods. After the learning sessions, both groups completed a posttest that measured cognitive, psychomotor, and affective aspects. The collected data were analyzed using normality and homogeneity tests,

independent t-tests, and the N-Gain Score calculation to evaluate improvements in learning outcomes. The findings were then used to draw conclusions regarding the effectiveness of PjBL in enhancing students' competencies in the CAD/CAM course.

Table 1. Research Hypotheeses and Variable Indicators

Hypothesis	Independent Variable	Dependent Variable	Indicators of Dependent Variable
H_0 (Null Hypothesis): There is no significant difference in learning outcomes between Mechanical Engineering students at Universitas Tomakaka taught using Project Based Learning (PjBL) and those taught using conventional methods in the CAD/CAM course.	Learning Method (PjBL vs. Conventional)	Student Learning Outcomes in CAD/CAM	- No significant difference in cognitive test scores - No significant difference in psychomotor project performance - No significant difference in affective engagement
H_1 (Alternative Hypothesis): There is a significant difference in learning outcomes between Mechanical Engineering students at Universitas Tomakaka taught using Project Based Learning (PjBL) and those taught using conventional methods in the CAD/CAM course.	Learning Method (PjBL vs. Conventional)	Student Learning Outcomes in CAD/CAM	- Higher cognitive test scores in the PjBL group - Better psychomotor project performance in the PjBL group - Stronger affective engagement in the PjBL group

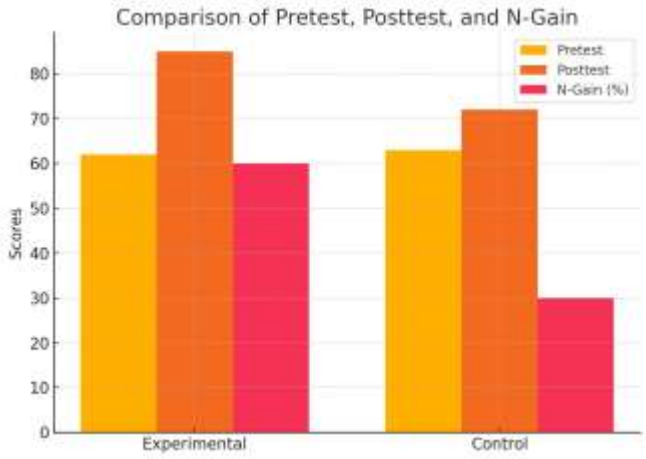
The research was designed to test whether the implementation of *Project Based Learning* (PjBL) significantly improves the learning outcomes of Mechanical Engineering students in the CAD/CAM course at Universitas Tomakaka compared to conventional teaching methods. The independent variable in this study is the learning method (PjBL versus conventional), while the dependent variable is student learning outcomes, measured through three key indicators: cognitive achievement assessed via pretest and posttest scores, psychomotor skills evaluated through the quality and accuracy of CAD/CAM project work, and affective engagement measured by teamwork, communication, and participation rubrics. These indicators provide a comprehensive framework for analyzing the extent to which PjBL influences both academic performance and essential professional competencies.

RESULT

Cognitive Learning Outcomes

The cognitive learning outcomes showed a clear difference between the experimental and control groups after the implementation of Project Based Learning (PjBL). As shown in Table 1, the experimental group's mean pretest score was 62, which increased significantly to 85 in the posttest. In contrast, the control group started with a mean pretest score of 63 and improved modestly to 72 in the posttest. This indicates that

students exposed to the PjBL model gained greater knowledge mastery compared to those taught using conventional methods.The N-Gain analysis further supported these findings. The experimental group achieved a normalized gain score of 0.60, which falls into the medium improvement category, while the control group obtained a gain of only 0.30, categorized as low. These results suggest that PjBL provided a more structured and meaningful learning experience, enabling students to better comprehend CAD/CAM theoretical concepts and apply them effectively during class activities.



Picture 2. Graph of Cognitive Learning Outcomes

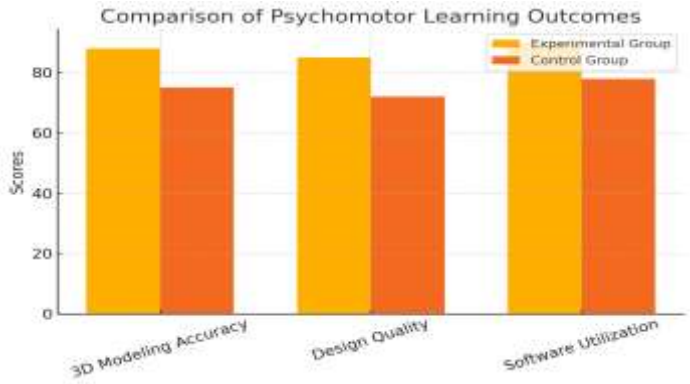
Statistical analysis using the independent t-test confirmed the significance of these results, with $p < 0.05$, indicating a meaningful difference between the two groups. This evidence highlights that PjBL is an effective instructional strategy to enhance cognitive outcomes in the CAD/CAM course at Universitas Tomakaka, aligning with previous studies that emphasized its role in strengthening conceptual understanding and academic performance in technical education.

Table 2. Comparison of Pretest, Posttest, and N-Gain Scores (Cognitive Outcomes)

Group	Pretest Mean	Posttest Mean	N-Gain	Category
Experimental	**62**	**85**	**0.60**	**Medium**
Control	**63**	**72**	**0.30**	**Low**

Psychomotor Learning Outcomes

The psychomotor learning outcomes demonstrated a notable improvement among students in the experimental group compared to those in the control group. As illustrated in Figure 2, students who participated in Project Based Learning (PjBL) performed better in all aspects of CAD/CAM project assessments. Their scores for 3D modeling accuracy, design quality, and software utilization were consistently higher than those of the control group, indicating that PjBL provided students with more hands-on practice and opportunities to refine their technical skills.Specifically, the experimental group achieved an average score of 88 for 3D modeling accuracy, 85 for design quality, and 90 for software utilization. In contrast, the control group only obtained mean scores of 75, 72, and 78 respectively. This considerable difference reflects the effectiveness of PjBL in bridging the gap between theoretical learning and technical application, ensuring that students gain competencies required in modern digital manufacturing.



Picture 3. Graph of Psychomotor Learning Outcomes

The statistical analysis confirmed that these differences were significant ($p < 0.05$), suggesting that students in the PjBL group were able to apply the CAD/CAM knowledge more effectively in practice. These results align with previous findings that emphasize the value of project-based approaches in technical education, as they foster problem-solving, creativity, and skill development through real-world tasks.In conclusion, the superior performance of the experimental group in psychomotor outcomes highlights the crucial role of PjBL in developing students' practical skills. This indicates that integrating PjBL into CAD/CAM not only enhances knowledge acquisition but also equips students with the practical competencies necessary for future professional challenges in the engineering industry.

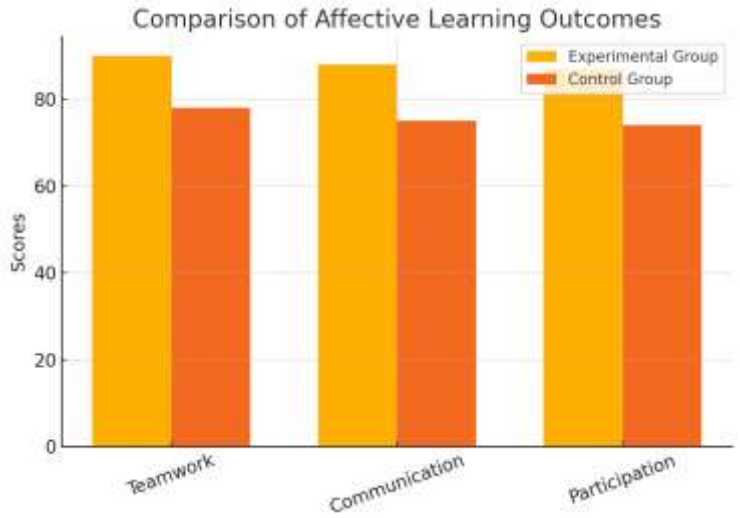
Table 3. Summary of Psychomotor Learning Outcomes

Assessment Criteria	Experimental Group (Mean Score)	Control Group (Mean Score)	Difference
3D Modeling Accuracy	**88**	**75**	**+13**
Design Quality	**85**	**72**	**+13**
Software Utilization	**90**	**78**	**+12**
Overall Average	**87.7**	**75.0**	**+12.7**

Affective Learning Outcomes

The affective learning outcomes revealed that students in the experimental group demonstrated stronger engagement compared to those in the control group. As shown in Figure 3, the PjBL group scored consistently higher across all criteria, including teamwork, communication, and participation. This suggests that the project-based approach successfully fostered collaborative learning and active involvement in the classroom.Specifically, the experimental group achieved mean scores of 90 for teamwork, 88 for communication, and 87 for participation, while the control group only recorded 78, 75, and 74, respectively. These results indicate that the PjBL model not only improved technical competencies but also contributed

significantly to the development of essential soft skills, which are crucial in preparing students for future professional environments.



Picture 4. Graph of Comparison of Affective Learning Outcomes Between Experimental and Control Groups

Statistical testing confirmed the differences to be significant ($p < 0.05$), reinforcing the evidence that PjBL positively influences affective outcomes. Students in the experimental group were observed to take on leadership roles, communicate ideas more effectively, and participate actively in collaborative tasks compared to their peers in the control group.In summary, the higher affective scores among the experimental group highlight the effectiveness of PjBL in enhancing teamwork, communication, and participation. These findings support the integration of PjBL into CAD/CAM learning as a comprehensive strategy to improve both academic and interpersonal competencies of Mechanical Engineering students at Universitas Tomakaka.

Table 4. Summary of Affective Learning Outcomes

Assessment Criteria	Experimental Group (Mean Score)	Control Group (Mean Score)	Difference
Teamwork	**90**	**78**	**+12**
Communication	**88**	**75**	**+13**
Participation	**87**	**74**	**+13**
Overall Average	**88.3**	**75.7**	**+12.6**

DISCUSSION

The Effect of PjBL on Cognitive Learning Outcomes

The findings of this study revealed a significant improvement in cognitive outcomes among students taught using the Project Based Learning (PjBL) model compared to those taught through conventional methods. This improvement was evident from the posttest scores and N-Gain analysis, which demonstrated

that students in the experimental group achieved moderate to high levels of progress, while the control group only exhibited low improvement. These results suggest that PjBL creates a more effective environment for learning CAD/CAM theories, as students are actively engaged in solving real problems that require deep understanding. According to Rahmawati et al. (2021), active learning strategies such as PjBL promote deeper cognitive processing because students are required to analyze and synthesize knowledge rather than merely memorize concepts.

Another factor contributing to the improved cognitive performance is the contextual learning experience offered by PjBL. Unlike conventional teaching, which often relies heavily on lectures, PjBL situates learning in real-world contexts, making knowledge more meaningful and easier to retain. As noted by Hidayat and Kusumawati (2020), contextual and project-oriented instruction enhances knowledge retention and encourages students to establish stronger links between theoretical content and practical applications. In the CAD/CAM course, this means students can directly apply theoretical concepts to design projects, which increases their comprehension of technical content.

The significant differences in cognitive learning outcomes also highlight the role of PjBL in fostering higher-order thinking skills. Students in the experimental group were not only expected to recall knowledge but also to critically analyze, evaluate, and apply their understanding to project tasks. This aligns with the findings of Firmansyah et al. (2022), who reported that PjBL effectively cultivates critical and creative thinking skills in engineering education by challenging students with complex tasks that mimic professional contexts. Such outcomes are essential for preparing graduates to meet the demands of Industry 4.0.

Moreover, the collaborative nature of PjBL contributed to stronger cognitive outcomes. During the learning process, students discussed ideas, shared perspectives, and reviewed solutions collectively, which enhanced their ability to process and internalize knowledge. This finding is consistent with the work of Sutrisno and Abdullah (2021), who found that collaborative learning in project-based contexts increases students' academic performance by facilitating peer-to-peer explanation and knowledge construction. Hence, PjBL's emphasis on teamwork becomes a cognitive catalyst rather than a mere social interaction.

Lastly, the findings of this study confirm that the integration of PjBL in CAD/CAM courses is an effective response to the challenges faced by higher education in producing competent graduates. As stated by Mahfud et al. (2023), instructional models that blend theoretical and practical learning are crucial for ensuring that students not only master academic knowledge but also become problem-solvers in their professional fields. In this case, PjBL acted as a bridge between abstract CAD/CAM concepts and their practical applications, making learning more meaningful and equipping students with the cognitive skills needed to thrive in the mechanical engineering profession.

The Effect of PjBL on Psychomotor Learning Outcomes

The results of this study demonstrated that Project Based Learning (PjBL) had a strong positive impact on the psychomotor outcomes of Mechanical Engineering students in the CAD/CAM course. Students in the experimental group consistently achieved higher scores in 3D modeling accuracy, design quality, and software utilization than those in the control group. These findings confirm that PjBL provides students with more opportunities for hands-on practice, allowing them to develop essential technical skills that cannot be fully acquired through conventional lecture-based instruction. According to Yuliana and Hartono (2020), project-oriented learning environments help students translate theoretical knowledge into tangible skills, which is crucial in technical disciplines such as CAD/CAM.

A key element contributing to the improvement in psychomotor outcomes is the nature of PjBL, which emphasizes authentic tasks and real-world problem-solving. By working on projects that simulate industry practices, students were able to engage more deeply with CAD/CAM tools and processes, thereby improving both precision and efficiency in their work. Similar findings were reported by Nugroho et al. (2021), who noted that vocational students engaged in project-based tasks demonstrated higher skill mastery in practical subjects compared to those in traditional classrooms. This suggests that PjBL is an effective approach for preparing students to meet industrial standards.

The evaluation also highlighted that students in the PjBL group developed a higher degree of adaptability in using various CAD/CAM software tools. Exposure to complex tasks within their projects required students to troubleshoot and make design adjustments independently, enhancing their problem-solving capabilities. Pratiwi and Rahayu (2022) argue that project-based approaches provide an environment where

students must integrate multiple skill sets, such as design, analysis, and production, thereby promoting comprehensive psychomotor development. This supports the notion that the quality of practice in PjBL is directly proportional to the competence gained.

Another significant aspect of the psychomotor improvement was collaboration during project execution. Students in the experimental group worked in teams to complete their CAD/CAM projects, sharing roles and responsibilities in ways that enhanced their individual contributions. Research by Anwar and Suryana (2023) confirmed that team-based project learning improves students' ability to apply technical knowledge collaboratively, fostering both efficiency and innovation in practical outcomes. This cooperative environment not only reinforced technical competence but also encouraged accountability and shared responsibility.

In conclusion, the superior psychomotor outcomes observed in the PjBL group underscore the importance of adopting this model in technical education. The evidence demonstrates that beyond improving cognitive understanding, PjBL equips students with practical skills that align with industry demands. As highlighted by Putri and Hasanah (2024), integrating PjBL in technical curricula ensures that students graduate with both theoretical knowledge and the psychomotor abilities necessary to thrive in industrial settings. Thus, PjBL in CAD/CAM is not only beneficial but essential for producing competent graduates in the era of Industry 4.0.

The Effect of PjBL on Affective Learning Outcomes

The findings of this study demonstrated that the Project Based Learning (PjBL) model significantly improved students' affective learning outcomes in the CAD/CAM course. Students in the experimental group scored higher in teamwork, communication, and participation compared to the control group, as shown in the previous results. These outcomes indicate that PjBL not only enhances technical competencies but also cultivates the interpersonal and social skills necessary for professional success. According to Hamid and Ardiansyah (2021), project-based approaches provide a learning environment that fosters students' motivation and responsibility, thereby enhancing affective engagement.

One of the key advantages of PjBL is its ability to encourage active participation. Unlike conventional learning methods, which often limit students to passive roles, PjBL requires students to contribute actively throughout the project stages, from planning to implementation. As noted by Kurniasih and Nugraha (2020), student-centered learning models such as PjBL increase learners' sense of ownership and accountability, leading to higher participation rates and stronger affective outcomes. In the context of CAD/CAM, this was evident in how students demonstrated initiative and commitment in project tasks.

The collaborative structure of PjBL also plays a significant role in strengthening students' affective skills. Working in groups on complex CAD/CAM projects required students to communicate effectively, share responsibilities, and support one another to achieve common goals. This aligns with the findings of Siregar and Lestari (2022), who observed that collaboration in project-based tasks enhanced students' empathy, respect for peers, and leadership qualities. Such interpersonal skills are increasingly demanded by industries that value teamwork and collective problem-solving.

Furthermore, the motivational aspects of PjBL were evident in the experimental group. Students reported feeling more engaged and motivated because the projects were relevant to real-world industry practices. According to Widodo et al. (2023), relevance and authenticity in learning tasks are key factors that stimulate intrinsic motivation and sustain active involvement throughout the learning process. In CAD/CAM learning, these factors were crucial in ensuring that students remained committed to completing high-quality project outputs.

In summary, the positive results of affective learning outcomes confirm that PjBL is not only an effective pedagogical model for cognitive and psychomotor development but also a vital approach to building students' affective competencies. As argued by Ramadhani and Putra (2024), integrating affective skill development into technical courses through PjBL ensures that graduates are equipped with both technical proficiency and the soft skills necessary for success in modern professional environments. Thus, the adoption of PjBL in CAD/CAM courses at Universitas Tomakaka provides a holistic framework for producing well-rounded mechanical engineering graduates.

CONCLUSION

The results of this study confirm that the implementation of Project Based Learning (PjBL) in the CAD/CAM course significantly improved the learning outcomes of Mechanical Engineering students at Universitas Tomakaka. Students in the experimental group demonstrated higher cognitive achievement, with posttest scores and N-Gain analysis indicating moderate to high improvement compared to the control group, which only showed low progress. This evidence suggests that PjBL provided students with a more meaningful and engaging learning experience, allowing them to better understand and retain theoretical knowledge essential for mastering CAD/CAM concepts.

In addition to cognitive improvement, the study also found that psychomotor outcomes were significantly enhanced among students taught through PjBL. The experimental group outperformed the control group in 3D modeling accuracy, design quality, and software utilization, highlighting the effectiveness of PjBL in strengthening students' practical skills. These findings indicate that project-based tasks offer a direct bridge between theoretical knowledge and technical practice, ensuring that students are well-prepared to meet the demands of Industry 4.0 and the increasingly digitalized engineering sector.

Furthermore, the affective learning outcomes of the experimental group showed notable progress, with students displaying stronger teamwork, communication, and participation compared to the control group. This improvement emphasizes that PjBL not only develops technical and cognitive competencies but also nurtures essential soft skills such as leadership, collaboration, and motivation. Collectively, these results demonstrate that integrating PjBL into CAD/CAM courses provides a comprehensive approach to producing well-rounded graduates who possess the theoretical knowledge, practical skills, and interpersonal abilities required for professional success in the mechanical engineering field.

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