**Ideguru : Jurnal Karya Ilmiah Guru**
p-ISSN 2527-5712 ; e-ISSN 2722-2195 ; Vol.10, No.3, September 2025
Journal homepage : https://jurnal-dikpora.jogjaprov.go.id/
DOI : https://doi.org/10.51169/ideguru.v10i3.2163
Accredited byKemendikbudristek Number: 79/E/KPT/2023(SINTA 3)
Dinas Dikpora DIY
ideguru Jurnal Karya Ilmiah Guru
*Research Articles* –Received: 16/11/2025 –Revised: 01/12/2025 –Accepted: 31/12/2025 –Published: 01/01/2026

# Effect of Project-Based Learning on Vocational High School Student's Cognitive and Psychomotor Competencies in CAD

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**Abstract:** This study investigates the effect of Project-Based Learning (PjBL) on students' cognitive understanding and psychomotor performance in the Computer Aided Design (CAD) subject, a core course within the Mechanical Engineering program at SMKN 1 Singosari. The research was motivated by the need to bridge the gap between theoretical instruction and real-world design competencies in vocational education. A quantitative descriptive approach was employed, with a total sampling technique involving all students enrolled in the CAD course during the ongoing semester. Data were collected through cognitive tests, practical performance assessments, and Likert-scale questionnaires to measure perceptions. The results revealed that students achieved high levels of cognitive mastery, with dominant correct responses on key CAD concepts such as part modeling, assembly environments, and technical file formats. Psychomotor evaluations indicated consistent practical performance, with a mean score of 82.36, while perception analysis reflected high levels of student engagement and satisfaction with the PjBL model. These findings suggest that PjBL effectively fosters integrated learning experiences that enhance technical understanding, practical skills, and student motivation. Consequently, the adoption of project-based strategies is recommended for vocational curricula to support competency-based education in technical fields.
**Keywords:** project-based learning; CAD; cognitive understanding; psychomotor skills.

## *Pengaruh Pembelajaran Berbasis Proyek terhadap Kompetensi Kognitif dan Psikomotorik Siswa SMK dalam Pembelajaran CAD*

***Abstrak:*** *Penelitian ini bertujuan untuk mengkaji pengaruh Pembelajaran Berbasis Proyek (PjBL) terhadap pemahaman kognitif dan kinerja psikomotorik siswa dalam mata pelajaran Desain Bantuan Komputer (CAD), yang merupakan mata pelajaran inti dalam program Studi Teknik Mesin di SMKN 1 Singosari. Penelitian ini didorong oleh kebutuhan untuk menjembatani kesenjangan antara pengajaran teoritis dan kompetensi desain di dunia nyata dalam pendidikan vokasi. Pendekatan deskriptif kuantitatif digunakan, dengan teknik sampling total yang melibatkan semua siswa yang terdaftar dalam mata pelajaran CAD selama semester berjalan. Data dikumpulkan melalui tes kognitif, penilaian kinerja praktis, dan kuesioner skala Likert untuk mengukur persepsi. Hasil menunjukkan bahwa siswa mencapai tingkat penguasaan kognitif yang tinggi, dengan respons benar yang dominan pada konsep-konsep CAD kunci seperti pemodelan bagian, lingkungan perakitan, dan format file teknis. Evaluasi psikomotorik menunjukkan kinerja praktis yang konsisten, dengan skor rata-rata 82,36, sementara analisis persepsi mencerminkan tingkat keterlibatan dan kepuasan siswa yang tinggi terhadap model PjBL. Temuan ini menunjukkan bahwa PjBL secara efektif memfasilitasi pengalaman belajar terintegrasi yang meningkatkan pemahaman teknis, keterampilan praktis, dan motivasi siswa. Oleh karena itu, penerapan strategi berbasis proyek direkomendasikan untuk kurikulum vokasi guna mendukung pendidikan berbasis kompetensi di bidang teknis.*
***Kata kunci****: pembelajaran berbasis proyek; CAD; pemahaman kognitif; keterampilan psikomotorik.*

## 1. Introduction

The rapid advancement of digital technologies within the manufacturing industry has redefined the competency requirements for vocational education, particularly in Mechanical Engineering programs. In this context, mastery of Computer Aided Design (CAD) software is considered a critical skill, enabling students to both conceptualize and construct precise digital representations of mechanical components. As a result, CAD has become a core subject in vocational school curricula. However,

p-ISSN 2527-5712 ; e-ISSN 2722-2195 DOI : https://doi.org/10.51169/ideguru.v10i3.2163

conventional teaching approaches that often rely on lectures and separate technical exercises have failed to develop a balanced integration between theoretical understanding and practical application. According to Fauzansyah *et al*. (2025), teaching practices that prioritize teacher control with minimal student engagement frequently fail to reflect real-world challenges encountered in modern design environments. Tembrevilla *et al*. (2024) further emphasize the importance of pedagogical frameworks that support experiential learning, where students engage with realistic scenarios. One instructional method that aligns with this need is project-based learning (PjBL), which provides opportunities for learners to solve problems collaboratively and apply knowledge in authentic contexts, thereby increasing motivation and cognitive depth (Lavado-Anguera *et al*., 2024).

Several recent studies have illustrated the positive influence of project-oriented instruction on various aspects of student learning in vocational settings (Zhou, 2023). Ibrahim & Rashid (2022) found that students involved in long-term design assignments developed stronger collaboration skills and demonstrated higher self-direction in their learning process. Nurtanto *et al*. (2020) also noted that active participation in real-life design tasks helped bridge the disconnect between conceptual understanding and manual skill development. While these findings support the implementation of project-based pedagogy, existing literature still lacks studies that explicitly focus on CAD instruction in secondary-level vocational schools. Ramadani *et al*. (2024) argue that the simultaneous measurement of both cognitive and technical abilities in CAD-focused courses has rarely been addressed in a single study. Moreover, as highlighted by Susanto *et al*. (2020) and Prasetya *et al*. (2024), descriptive quantitative research approaches remain underexplored in assessing the extent to which such learning models enhance overall student achievement. This identifies a significant need for more comprehensive evaluations that examine both knowledge acquisition and practical proficiency in CAD-related vocational education.

To address this gap, the present study examines how project-focused instructional strategies contribute to strengthening students' conceptual understanding and practical competencies in the CAD subject. Implementing project-oriented learning is positioned as a pedagogical response to the persistent disconnect between theoretical knowledge and hands-on design skills that vocational learners must master. Prior research underscores the importance of embedding authentic project experiences to mirror workplace expectations, as emphasized by Yudiono *et al*. (2021), while Rahmadani *et al*. (2024) and Peng *et al*. (2023) highlight that such approaches can enhance technical mastery and improve readiness for real engineering tasks. Building upon these insights, this study aims to evaluate the extent to which project-based learning can improve students' cognitive and psychomotor outcomes in CAD instruction. The findings are expected to offer meaningful contributions for vocational educators and policymakers by providing empirical evidence on effective, industry-aligned instructional strategies that support competency-based learning in mechanical engineering education.

## 2. Materials and Methods

This study employed a descriptive quantitative research design similiari Fauzansyah *et al*. (2025), to examine the influence of project-based learning on students' conceptual understanding and practical proficiency in Computer Aided Design within the Mechanical Engineering program at SMKN 1 Singosari. The entire population of students enrolled in the CAD course during the semester was included through total population sampling to ensure comprehensive coverage of learner performance. Data were collected using two primary instruments, namely a cognitive assessment consisting of concept-based test items and a psychomotor performance rubric used to evaluate students' technical drawing tasks. The implementation of project-based learning followed structured phases that included problem identification, project planning, design development, and presentation of outcomes. Quantitative data were analyzed using descriptive statistical techniques, including the calculation of means, score distributions, and categorical interpretations of learning outcomes. This methodological approach enabled a systematic portrayal of students' learning achievements across both cognitive and practical domains.

## 3. Result and Discussion

The adoption of project-based learning (PjBL) in the Computer Aided Design (CAD) course at SMKN 1 Singosari yielded substantial and measurable learning gains across the cognitive domain, reflecting students' strengthened mastery of core design concepts. The cognitive test results demonstrated that learners consistently identified correct functions, templates, and file formats—showing their ability

p-ISSN 2527-5712 ; e-ISSN 2722-2195 DOI : https://doi.org/10.51169/ideguru.v10i3.2163

to distinguish between part models, assembly environments, and sheet metal tools. The five highest-frequency responses presented in Table 1 further confirm that fundamental competencies were effectively internalized, suggesting that students not only memorized procedures but also comprehended the conceptual logic behind CAD operations. This pattern mirrors the conclusions of Gutiérrez de Ravé *et al*. (2025), who emphasized that contextualized, real-task learning situations improve conceptual accuracy and reduce misconceptions. Similarly, Zhang (2023) argued that iterative exposure to CAD tasks within PjBL settings reinforces learners' cognitive schemas, enabling them to more quickly recognize patterns in digital modeling tasks. The evidence from this study supports these perspectives, indicating that the structured project stages ranging from problem definition to design validation provided a conducive environment for developing higher-order cognitive skills relevant to technical drawing and mechanical design.

Beyond cognitive development, the PjBL approach also contributed significantly to psychomotor and affective improvements that are essential in vocational learning. Psychomotor evaluation results showed consistent practical proficiency, demonstrated by the average performance score of 82.36 and the clustering of scores around the median and mode of 80. These results imply that students became increasingly adept at executing procedural steps such as sketching, extruding, assembling, and refining 3D models with precision. This aligns with the observations of Lugo Vélez *et al*. (2021), who found that complex project tasks promote procedural fluency and fine-motor accuracy in digital design environments. Affective engagement further reinforced these outcomes, as captured through the Likert-scale perceptions in Table 3. High ratings on indicators related to teacher guidance, project relevance, and student involvement reveal strong motivation and collaborative interaction key elements that sustain persistence in demanding technical subjects. Taken together, these findings illustrate that PjBL creates a holistic learning ecosystem where cognitive understanding, practical competence, and emotional engagement interact synergistically to support deeper mastery of CAD competencies.

In the psychomotor domain, student performance demonstrated notable progress that reflects their increasing capability to perform CAD modeling tasks with precision and confidence. As presented in Table 2, the practical test scores reached an average of 82.36, with both the median and mode at 80, placing the overall performance in the "Good" category. These quantitative results indicate that students were not only able to complete the assigned modeling tasks but were also able to do so consistently across the class population. The clustering of scores around the same central values suggests a uniform level of skill acquisition, where most students internalized the procedural steps required to generate accurate 2D sketches, extrusions, feature modifications, and assemblies. Such consistency is a key indicator of successful skills-based learning in vocational contexts, where standardization of outcomes across learners often determines readiness for real-world technical tasks.

Table 1. Most Frequent Answers on Cognitive CAD Test (First 5 Items)

| No. | Test Item Description | Most Frequent Answer |
|---|---|---|
| 1 | Template used in Autodesk Inventor | a. Part |
| 2 | Function for sheet metal design | d. Sheet Metal |
| 3 | Tool used to assemble parts | b. Assembly |
| 4 | File format for part design | a. ipt |
| 5 | Toolbar group shown in the image | b. Create |

The improvement in technical execution resonates strongly with the findings of Wibisono *et al*. (2020), who observed that iterative engagement with 3D modeling exercises enhances learners' fine-motor proficiency and strengthens their ability to manipulate complex software tools. When students repeatedly practice generating geometric shapes, adjusting constraints, and refining dimensions, they develop procedural fluency an essential skill for transitioning from basic modeling to more advanced digital fabrication tasks. In this study, similar evidence emerged as students showed increasing independence in navigating the interface, selecting appropriate feature commands, and correcting errors without excessive teacher intervention. This pattern reflects the cognitive–motor integration described in vocational learning theory, where repeated cycles of practice, reflection, and refinement help students transfer conceptual understanding into efficient motor actions during technical tasks.

Furthermore, the role of project complexity in shaping students' psychomotor development is

p-ISSN 2527-5712 ; e-ISSN 2722-2195 DOI : https://doi.org/10.51169/ideguru.v10i3.2163

an important dimension of the findings. As project stages progressed from simple part modeling to multi-component assemblies, students were required to engage with higher levels of precision, spatial reasoning, and workflow management. This aligns with Lugo Vélez *et al*. (2021), who argued that escalating task complexity challenges learners to develop procedural adaptability and fosters deeper engagement with CAD tools. The data in this study show that students responded positively to these challenges, as evidenced by their improved accuracy, reduced error frequency, and more efficient use of time during evaluations. These improvements also correspond to an observed increase in student confidence and autonomy, characteristics often associated with mastery-level competence in vocational training. Collectively, these psychomotor gains illustrate that PjBL does more than facilitate completion of isolated tasks it creates conditions where learners progressively construct, refine, and internalize technical skills required for professional practice in mechanical design environments.

Table 2. Summary of Practical Skill Assessment Scores

| Metric | Score |
|---|---|
| Mean | 82.36 |
| Median | 80.00 |
| Mode | 80.00 |

Students also responded positively to the affective components of the instruction, demonstrating that Project-Based Learning (PjBL) not only strengthened their technical competence but also fostered emotional and motivational engagement. As indicated in Table 3, the Likert-scale responses reveal consistently high levels of satisfaction, particularly regarding teacher guidance, the relevance of project tasks, and the degree of student involvement. The highest-rated statement "The teacher helps students understand project problems" received an average score of 3.70 out of 4, which underscores the vital role of instructional support in helping students navigate complex design challenges. Such positive perceptions reflect a conducive learning climate in which students feel supported, valued, and guided throughout the learning process. This is particularly important in CAD instruction, where software intricacies and technical requirements can easily overwhelm beginners if adequate scaffolding is not provided.

These findings reinforce the view of Dincă *et al*. (2023), who argue that affective support forms a central pillar of successful project-based pedagogy, enabling learners to build confidence and reduce anxiety when working on ambitious design projects. In alignment with this perspective, the results from SMKN 1 Singosari reveal that students perceive the learning environment as collaborative and student-centered, which is consistent with the fundamental principles of PjBL. When learners are given the opportunity to choose project topics, explore solutions, and discuss ideas openly, they tend to experience a greater sense of ownership toward their learning. This sense of autonomy contributes to heightened motivation, persistence, and willingness to engage in reflective problem-solving, all of which are essential for mastering complex tasks such as digital modeling and multi-component assembly. The strong affective response noted in this study suggests that the structured yet flexible nature of PjBL aligns well with the psychological needs of vocational learners.

Furthermore, emotional engagement plays a pivotal role in sustaining students' commitment to technically demanding subjects like CAD. Dobranici *et al*. (2025), note that emotional involvement enhances not only motivation but also endurance when students encounter modeling errors, constraints misalignments, or assembly failures common obstacles in design-based coursework. In this study, students' high ratings for teacher support, project relevance, and peer collaboration indicate that they experienced a learning process characterized by encouragement, meaningful task connection, and shared responsibility. These affective conditions enable learners to persist through challenges and ultimately achieve deeper conceptual and practical mastery. Collectively, the affective outcomes observed in this research highlight that PjBL contributes to a holistic learning environment where emotional, social, and cognitive factors work synergistically to enhance overall learning effectiveness in vocational CAD education.

Table 3. Mean Scores of Likert Scale Items (Top 5 Rated)

| No | Statement | Average Score |
|---|---|---|
| 1 | Teacher helps students understand project problems | 3.70 |
| 2 | Teacher supports project planning and execution | 3.55 |
| 3 | Teacher links project to industry relevance | 3.52 |
| 4 | Students are involved in choosing project topics | 3.33 |
| 5 | Teacher explains project objectives clearly | 3.37 |

p-ISSN 2527-5712 ; e-ISSN 2722-2195 DOI : https://doi.org/10.51169/ideguru.v10i3.2163

Overall, the integration of project-based learning in CAD instruction appears to enhance holistic competence. Petrov (2025) point out that PjBL narrows the gap between school and industry expectations, a principle evident in this study's results. Meanwhile, Vasilev (2024) and Prasetya *et al*. (2025) demonstrated that aligning assessment with real-world outcomes contributes to learner readiness. The total sampling method employed here (n = all students enrolled in CAD) enhances the credibility of the generalizations drawn, echoing Zhao and Degen (2025) argument for inclusive sampling in TVET research. The triangulated improvement across domains observed here resonates with recent literature by English (2020), who emphasize multi-domain integration in STEM project design.

## 4. Conclusion and Suggestions

The implementation of the Project-Based Learning (PjBL) model at SMKN 1 Singosari produced clear and measurable improvements across the cognitive, psychomotor, and affective domains in the Computer Aided Design (CAD) course, directly answering the research objectives. Cognitive assessment results showed strong conceptual mastery, as indicated by students' dominant correct responses on essential CAD concepts such as template selection, assembly functions, sheet metal operations, and part file formats. Psychomotor competence also increased significantly, supported by a mean practical performance score of 82.36, with a median and mode of 80, demonstrating enhanced modeling precision, procedural fluency, and growing independence during design tasks. Affective engagement reinforced these findings, with perception data revealing high student motivation particularly the item "The teacher helps students understand project problems," which received a 3.70/4 showing that PjBL fosters supportive learning interactions. These integrated outcomes confirm that PjBL strengthens vocational learners' competencies in line with industry-oriented expectations. Schools are encouraged to adopt PjBL through authentic project scenarios, adequate CAD facilities, and sustained teacher professional development. Future research should explore the long-term impact of PjBL on employability skills, conduct cross-subject comparisons, and incorporate virtual design tools or CAD-based learning analytics to deepen understanding of technology-enhanced vocational learning.

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