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# Improving 3D Design Competence through Project-Based Learning among Mechanical Machining Students at SMKS PGRI 3 Malang

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## ABSTRACT

Learning outcomes in three-dimensional *Computer Aided Design* (CAD) among vocational high school students are still not optimal, as indicated by low student engagement and limited competency achievement. This study aims to improve students' 3D design competence through the implementation of *Project-Based Learning* (PjBL) in Grade X Machining Engineering students at SMKS PGRI 3 Malang. This research employed a classroom action research design conducted in two cycles, each consisting of planning, action, observation, and reflection stages. The subjects of this study were 31 students. The research instruments included learning outcome tests, observation sheets, and documentation. The results showed that the average student score increased from 64.74 in the pre-action stage to 83.23 in Cycle I and 85.32 in Cycle II. Learning mastery improved from 3% to 87% and reached 100% in Cycle II, with an *N-gain* value of 0.58 categorized as moderate. Classroom observation and documentation also indicated a high level of student engagement throughout the learning process. Therefore, the implementation of *Project-Based Learning* is effective in improving students' 3D design competence.

**Informasi Artikel**

**Kata Kunci:**

cad 3d;
kompetensi desain;
*project-based learning*;
siswa smk;
teknik pemesinan.

## ABSTRAK

Pembelajaran *Computer Aided Design* (CAD) tiga dimensi pada siswa SMK masih menunjukkan hasil yang belum optimal, ditandai dengan rendahnya keterlibatan dan pencapaian kompetensi siswa. Penelitian ini bertujuan untuk meningkatkan kompetensi desain 3D melalui penerapan model *Project-Based Learning* (PjBL) pada siswa kelas X Teknik Pemesinan SMKS PGRI 3 Malang. Penelitian ini menggunakan metode penelitian tindakan kelas yang dilaksanakan dalam dua siklus yang meliputi tahap perencanaan, pelaksanaan tindakan, observasi, dan refleksi. Subjek penelitian berjumlah 31 siswa. Instrumen penelitian meliputi tes hasil belajar, lembar observasi, dan dokumentasi. Hasil penelitian menunjukkan bahwa nilai rata-rata siswa meningkat dari 64,74 pada pra tindakan menjadi 83,23 pada siklus I dan 85,32 pada siklus II. Ketuntasan belajar meningkat dari 3% menjadi 87% dan 100%, dengan nilai *N-gain* sebesar 0,58 dalam kategori sedang. Observasi dan dokumentasi kelas juga menunjukkan tingkat keterlibatan siswa yang tinggi selama proses pembelajaran. Dengan demikian, penerapan model *Project-Based Learning* efektif dalam meningkatkan kompetensi desain 3D siswa.

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## 1. Introduction

As industries increasingly rely on technical expertise, vocational education has taken on a central role in equipping the workforce with job-ready competencies [1], [2], [3]. Beyond theoretical mastery, graduates of Vocational High Schools (SMKs) are expected to translate what they learn into practical skills relevant to their chosen field [1]. Within the Mechanical Machining program specifically, one core competency students must develop is producing accurate three-dimensional (3D) designs using Computer-Aided Design (CAD) software. In today's digitally driven manufacturing sector, command of such engineering design software has become indispensable to the product design process [4].

In practice, however, CAD instruction in schools tends to remain procedural [5]: students are guided through software operation steps with little exposure to the design reasoning behind them. Such surface-level learning tends to dampen student engagement and cap learning outcomes below their potential [6], while a teacher-centered classroom further constrains opportunities for students to build critical thinking and problem-solving skills [7].

Project-Based Learning (PjBL) offers a promising response to these challenges. Centered on completing authentic projects, PjBL positions students as active participants who collaborate and tackle real-world problems as part of the learning process [8], while also creating space for conceptual knowledge to merge with hands-on skill-building, giving the learning experience greater meaning [1].

A growing body of evidence supports PjBL's effectiveness in vocational settings: it has been linked to gains in learning outcomes, motivation, and technical skill development [7], stronger engagement and practical competence in engineering education [2], and measurable competency growth when learning is anchored in contextual, real-world activities [9]. Beyond these outcomes, PjBL has also been associated with sharper critical thinking, greater creativity, and improved achievement among vocational high school students [2], [10], [11] — collectively pointing to its potential to elevate the quality of engineering education, including instruction in computer-aided design [12], [13], [14].

While prior studies have established that Project-Based Learning generally improves learning outcomes, motivation, and engagement in vocational settings [7], [2], [9], [10], [11], most of this evidence rests on general learning-outcome measures rather than an explicit, rubric-based assessment of 3D design competence itself — that is, the specific ability to produce accurate, neat, and specification-compliant 3D models. Moreover, limited attention has been given to first-year (Grade X) Mechanical Machining students who are learning 3D CAD for the first time, and who therefore face the compounded challenge of learning CAD software operation and 3D design reasoning simultaneously, within a Classroom Action Research design that tracks this competence cycle by cycle. This study addresses that gap by analyzing the improvement of 3D design competence — operationalized through an explicit performance rubric — among Grade X Mechanical Machining students at SMKS PGRI 3 Malang through the implementation of Project-Based Learning.

## 2. Research Method

This study was designed as Classroom Action Research (CAR) to improve students' 3D design competence through implementation of the Project-Based Learning (PjBL) model in the Computer-Aided Design (CAD) course, unfolding through the familiar planning–action–observation–reflection cycle [11], [15]. Before the intervention began, preliminary observation pointed to low 3D CAD design competence among students, evidenced by a limited grasp of design procedures and low engagement in class — a baseline condition detailed further in Section 3.1.

At the planning stage, the researcher built a PjBL-based instructional design for 3D CAD — comprising teaching modules, project worksheets, and the research instruments [15], [16] — with the target of having students collaboratively produce a 3D component meeting the design accuracy, neatness, and specification-conformity criteria detailed below. This design was then carried out in the action stage through project-based 3D design activities, while the observation stage tracked student activity and engagement as the process unfolded [7]. Each cycle was carried out over eight meetings (16 meetings in total across both cycles), each consisting of five instructional class hours held from 10.40 a.m. to 3.15 p.m. In both cycles, students worked on the same project brief: modeling a pipe elbow component (Figure 1) in Autodesk Inventor, covering the stages of interpreting the technical drawing, constructing the 3D geometry, and verifying dimensional accuracy against the design specification. In the reflection stage, each cycle's outcome was evaluated against a predetermined success indicator: the action was considered successful, and the cycle terminated, once all students (100%) achieved the Minimum Mastery Criterion (MMC) with a class N-gain of at least the moderate category ($\geq 0.3$). In Cycle I, this indicator was not yet fully met — 87% of students achieved the MMC, short of the 100% threshold — and reflection identified uneven understanding of design concepts among group members and insufficient task coordination as contributing factors. Based on this reflection, improvements were implemented in Cycle II, namely clearer task instructions, more structured task distribution, and continuous guidance throughout project implementation [15], [17]. In Cycle II, the success indicator was met, and the action research was terminated after two cycles.

The research subjects were 31 Grade X Mechanical Machining students at SMKS PGRI 3 Malang during the 2025/2026 academic year, determined as the target of the action based on preliminary observation indicating low 3D CAD design competence, rather than through a probability or purposive sampling procedure intended for statistical inference — consistent with the single-class, single-site nature of Classroom Action Research. The research instruments consisted of (1) a learning achievement test measuring 3D design competence, (2) a student activity observation sheet, and (3) documentation. 3D design competence was operationalized through a four-level performance rubric (4 = very good, 3 = good, 2 = fair, 1 = poor) covering three indicators: design accuracy (the extent to which the model's dimensions and geometry match the design brief), model neatness (the visual cleanliness and consistency of the 3D model), and conformity with project specifications (compliance with the parameters set in the project brief). The three indicators were weighted equally in the raters' judgment. Rather than being derived from a fixed arithmetic formula, each student's final

competence score (reported on a 0–100 scale in Table 1 and Table 2) was determined holistically by the two raters, who used the four-level descriptors as a qualitative reference and translated their joint judgment into a 0–100 score following the school's standard CAD assessment convention; this holistic approach also accounts for the fine-grained score variation observed in Table 2, which a coarse four-level rubric alone could not produce. The validity of the instruments was established through expert judgment involving the CAD subject teacher, who reviewed the relevance, clarity, and appropriateness of the rubric indicators prior to use. To resolve scoring discrepancies between the two raters — the subject teacher and the researcher — using the same rubric; scoring discrepancies were discussed and resolved through consensus before final scores were recorded. The Minimum Mastery Criterion (MMC) used in this study was 75.

The data were analyzed using a descriptive quantitative approach. The improvement in students' learning outcomes was determined by calculating the mean score and the percentage of learning mastery using the following formula:

$$\bar{x} = \frac{\sum x}{N}$$

$$P = \frac{n}{N} \times 100\%$$

In Equation (1), $\bar{x}$ represents the mean score, $x$ represents the score obtained by each student, $N$ represents the total number of students, $P$ represents the percentage of learning mastery, and $n$ represents the number of students who achieved the Minimum Mastery Criterion (MMC).

To measure the magnitude of improvement between cycles relative to the theoretical maximum score, the normalized gain (N-gain) was calculated using the following formula: $g = (S_{post} - S_{pre}) / (S_{max} - S_{pre})$. In Equation (2), $S_{post}$ represents the class average score after the action in the given cycle, $S_{pre}$ represents the class average score before the action (baseline), and $S_{max}$ represents the maximum possible score (100).

It should be noted that because this study employed a Classroom Action Research design without a comparison or control group, the N-gain value is used descriptively — to indicate the magnitude of improvement across cycles relative to the theoretical maximum — rather than as evidence of a causal effect of the Project-Based Learning intervention in the strict experimental sense.

The observation data were analyzed to determine the improvement in students' learning activities and engagement during the project-based learning process. The results of this analysis were used as the basis for reflection to improve the learning process in each subsequent cycle [7], [15].

The interpretation of the N-gain values in this study refers to the categories of learning improvement, namely high (≥ 0.7), moderate (0.3–0.7), and low (< 0.3). These categories were used to determine the effectiveness of the learning model in improving students' competencies [18].

## 3. Result and Discussion

### 3.1 Research Results

The findings presented here stem from implementing the PjBL model in 3D CAD learning among 31 Grade X Mechanical Machining students at SMKS PGRI 3 Malang. Assessment data show that every student's learning outcomes improved following their participation in the project-based learning process.

The class average score rose steadily across both cycles, as summarized in Table 1.

**Table 1** Improvement of Students' Learning Outcomes

| No. | Assessment Item | Pre-Action | Cycle I | Cycle II |
|---|---|---|---|---|
| 1 | Lowest Student Score | 60 | 70 | 75 |
| 2 | Highest Student Score | 78 | 90 | 95 |
| 3 | Class Average Score | 64.74 | 83.23 | 85.32 |
| 4 | Learning Mastery | 3% | 87% | 100% |
| 5 | N-gain | – | 0.52 | 0.58 |

Based on Table 1, the class average score increased markedly from 64.74 in the pre-action stage to 83.23 in Cycle I and further increased to 85.32 in Cycle II. This indicates an improvement of 20.58 points from the initial condition to Cycle II.

The percentage of learning mastery also improved, increasing from 3% in the pre-action stage to 87% in Cycle I and reaching 100% in Cycle II. These results indicate that all students achieved the Minimum Mastery Criterion (MMC) by the end of Cycle II.

Furthermore, the lowest student score increased from 60 to 75, while the highest score improved from 78 to 95. The N-gain value of 0.58 in Cycle II indicates that the improvement in learning outcomes was categorized as moderate.

**Table 2** Individual Student Scores Across the Pre-Action, Cycle I, and Cycle II Assessments (N = 31)

| No. | Code | Pre-Action | Cycle I | Cycle II |
|---|---|---|---|---|
| 1 | S1 | 68.00 | 90.00 | 89.00 |
| 2 | S2 | 63.00 | 82.00 | 85.00 |
| 3 | S3 | 64.00 | 84.00 | 85.00 |
| 4 | S4 | 60.00 | 70.00 | 75.00 |
| 5 | S5 | 65.00 | 84.00 | 85.00 |
| 6 | S6 | 70.00 | 90.00 | 88.00 |
| 7 | S7 | 65.00 | 86.00 | 87.00 |
| 8 | S8 | 70.00 | 90.00 | 90.00 |
| 9 | S9 | 64.00 | 83.00 | 86.00 |
| 10 | S10 | 64.00 | 88.00 | 90.00 |
| 11 | S11 | 65.00 | 86.00 | 87.00 |
| 12 | S12 | 65.00 | 85.00 | 87.00 |
| 13 | S13 | 66.00 | 88.00 | 90.00 |
| 14 | S14 | 64.00 | 87.00 | 86.00 |
| 15 | S15 | 63.00 | 75.00 | 82.00 |
| 16 | S16 | 64.00 | 86.00 | 88.00 |
| 17 | S17 | 60.00 | 70.00 | 75.00 |
| 18 | S18 | 62.00 | 84.00 | 85.00 |
| 19 | S19 | 65.00 | 89.00 | 95.00 |
| 20 | S20 | 64.00 | 79.00 | 88.00 |
| 21 | S21 | 65.00 | 90.00 | 88.00 |
| 22 | S22 | 64.00 | 85.00 | 87.00 |
| 23 | S23 | 60.00 | 70.00 | 75.00 |
| 24 | S24 | 62.00 | 84.00 | 81.00 |

| No. | Code | Pre-Action | Cycle I | Cycle II |
|---|---|---|---|---|
| 25 | S25 | 60.00 | 70.00 | 75.00 |
| 26 | S26 | 63.00 | 85.00 | 82.00 |
| 27 | S27 | 64.00 | 83.00 | 87.00 |
| 28 | S28 | 64.00 | 86.00 | 88.00 |
| 29 | S29 | 62.00 | 84.00 | 83.00 |
| 30 | S30 | 78.00 | 82.00 | 88.00 |
| 31 | S31 | 74.00 | 85.00 | 88.00 |

*Note: Student names are anonymized (S1–S31) to protect the privacy of minor participants. The scores correspond to the aggregate figures reported in Table 1.*

The individual-level assessment results tell the same story: every student's scores rose after the PjBL model was introduced, consistent with an improvement in their understanding and skills in 3D design following the introduction of project-based learning.

The project-based learning process was carried out through collaborative 3D model design activities. Students actively discussed design concepts and implemented their designs using Computer-Aided Design (CAD) software. To support the research findings, documentation of the learning activities is presented in Figure 1.

**Figure 1** Students' Learning Activities during Project-Based Learning in 3D Computer-Aided Design (CAD)

Based on Figure 1, students were observed to be actively engaged throughout the learning process, participating in discussions, design planning, and hands-on modeling activities. This observation is corroborated by the affective (Sikap) score recorded by the subject teacher at the end of the course, which averaged 86.67 (n = 27; four students' scores were not recorded) on the school's 0–100 scale — categorized as "very good" under the school's assessment rubric. It should be noted that engagement was documented descriptively through classroom observation and photographic records rather than through a cycle-by-cycle instrument with indicator-level scoring; consequently, this finding is reported as a descriptive observation of engagement during the intervention rather than as a measured increase across cycles.

### 3.2 Discussion

Taken together, these results are consistent with an improvement in students' learning outcomes in the 3D CAD course following the implementation of the Project-Based Learning model [2], [13], [19]. As this study relied on a single-group, non-comparative Classroom Action Research design without inferential statistical testing, the improvements discussed below are interpreted descriptively rather than as evidence of statistically significant or causally proven effects. During the pre-action stage, the students' average score was relatively low at 64.74, with a learning mastery rate of only 3%, indicating that the learning process had not yet been optimal.

By Cycle I, the average score had climbed to 83.23 and the mastery rate to 87% — gains attributable to project-based learning's capacity to draw students into active participation, visible in their heightened engagement during discussions, design planning, and project completion.

However, several challenges were still identified during Cycle I, including insufficient coordination among group members and uneven understanding of design concepts. Therefore, improvements were made in Cycle II by providing clearer instructions, more structured task distribution, and continuous guidance throughout the project implementation process.

As a result, the average score increased to 85.32 in Cycle II, with the learning mastery rate reaching 100%. These findings indicate that most students were able to understand the design concepts and apply them effectively in 3D design projects. The improvement in learning outcomes not only reflects higher academic achievement but also indicates positive changes in students' learning processes [20], [21]. The implementation of the Project-Based Learning model encouraged students to participate actively in learning through design activities, discussions, and collaborative project completion [8], [19]. Such engagement enabled students to construct knowledge independently within meaningful learning contexts, making the concepts easier to understand and apply in 3D design practice.

Furthermore, when comparing pre-action scores with Cycle II results, all 31 students demonstrated improvement, indicating that the Project-Based Learning model was able to accommodate students with different levels of ability [19]. It should be noted that this improvement reflects the overall pre-action-to-Cycle-II trend; a subset of students recorded a slight decrease from Cycle I to Cycle II despite finishing above their baseline, consistent with the normal fluctuation expected in classroom-based skill development. These findings also suggest that project-based learning provides more equitable learning opportunities for students with diverse competencies. It enables students to learn actively, collaboratively, and contextually, resulting in deeper conceptual understanding [2], [5], [22].

The increase in the N-gain value from 0.52 to 0.58, both within the moderate category, reflects a consistent upward trend in students' competencies across the two cycles. As this study used a single-group, non-comparative design, this trend is reported descriptively as the magnitude of change observed, rather than as causal evidence of the intervention's effectiveness. These findings are consistent with previous studies reporting that Project-Based Learning effectively enhances student engagement, critical thinking skills, and practical competencies in vocational education [2], [10], [23]. Moreover, project-based learning provides authentic learning experiences that enable students to connect theoretical concepts with real-world applications [19], [24].

The findings of this study are also consistent with previous research demonstrating that the Project-Based Learning model significantly improves students' learning outcomes and engagement [7]. In addition to providing authentic and contextual learning experiences that enhance students' understanding of the subject matter, project-based learning also plays an important role in developing twenty-first-century skills, including critical thinking, collaboration, and creativity [25], [26].

Therefore, the improvements observed in this study were not only quantitative but also reflected an overall enhancement in the quality of the learning process [27].

## 4. Conclusion

Implementing the Project-Based Learning model in three-dimensional Computer-Aided Design (3D CAD) instruction proved effective in strengthening the competencies of Grade X Mechanical Machining students at SMKS PGRI 3 Malang. This improvement was reflected in the marked increase in students' learning outcomes, with the class average score rising from 64.74 in the initial condition to 85.32 at the end of the second cycle, accompanied by an increase in the learning mastery rate from 3% to 100%. Furthermore, comparing pre-action scores with Cycle II results, all 31 students demonstrated improved learning outcomes regardless of their initial ability level, suggesting that the Project-Based Learning model was able to accommodate students with varying competencies within this classroom action research context. As this study did not include a comparison group taught through conventional instruction, this finding should be interpreted as evidence of within-class improvement across two cycles rather than as a direct comparison with conventional teaching methods.

Beyond competency gains, classroom observation also indicated active student engagement throughout the learning process — most visibly in discussion, collaboration, and the independent, systematic completion of design projects — though this was documented descriptively rather than measured through a cycle-by-cycle instrument. Project-based learning provided a more contextual and meaningful learning experience, enabling students not only to understand theoretical concepts but also to apply them effectively in 3D design practice. This finding is further reflected in the N-gain value of 0.58 (moderate category), which describes the magnitude of improvement observed within this single-group design rather than serving as causal evidence of the model's effectiveness.

The findings of this study reinforce the importance of integrating authentic projects into vocational education to improve both the learning process and learning outcomes simultaneously [28]. Nevertheless, the successful implementation of the Project-Based Learning model requires careful planning, particularly in terms of time management and continuous guidance throughout project implementation. Therefore, the effectiveness of this learning model can be further enhanced through well-designed instructional strategies, effective time management, and sustained student supervision to maximize and equalize competency development among students [29], [30]. These findings are also consistent with previous studies emphasizing the importance of project-based learning in improving the quality of vocational education [19], [26].

## Study Limitations

Several limitations of this study warrant consideration when interpreting the findings above. First, the classroom action research design did not include a control or comparison group, and the researcher acted simultaneously as the class teacher and the primary instrument for reflection and assessment, which may introduce teacher-researcher bias in observing and interpreting students' progress. Second, because the study was conducted across sequential cycles without a comparison group, part of the observed improvement may be attributable to practice and maturation effects — that is, students becoming more familiar with the CAD software, the assessment rubric, and the project routine over time — rather than solely to the Project-Based Learning intervention itself. Third, as this research involved a single class of 31 Grade X Mechanical Machining students at one vocational school, the findings are context-specific and should not be generalized to other grade levels, study programs, or school settings without further investigation. Future studies employing comparison-group designs across multiple classes or schools are recommended to further verify the effectiveness of Project-Based Learning in improving 3D CAD design competence. Finally, student engagement in this study was documented descriptively through classroom observation and photographic records rather than through a structured, cycle-by-cycle observation instrument with indicator-level scoring; future action research is encouraged to adopt such an instrument to allow engagement to be tracked and reported quantitatively across cycles.

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