Problem-based learning in orthogonal projection drawing: A quasi-experimental study on vocational machining students' technical drawing achievement

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Abstract: This study examined the implementation of Problem-Based Learning (PBL) and its effect on Grade X Machining Engineering students' cognitive achievement in Technical Drawing, particularly orthogonal projection. The study used a quantitative quasi-experimental design with a non-equivalent control group. The participants were 70 students at SMK Negeri 5 Padang, divided into an experimental class taught using PBL and a control class taught using conventional instruction. Data were collected through pretest and post-test scores using a validated multiple-choice test on orthogonal projection. The final instrument consisted of 28 valid items with a KR-20 reliability coefficient of 0.914. Descriptive statistics, Shapiro-Wilk normality tests, Levene's homogeneity test, and an independent samples t-test were used for data analysis. The results showed that both groups improved after instruction, but the experimental class achieved a higher increase. The mean score of the experimental class rose from 53.57 to 79.28, while the control class increased from 53.67 to 64.29. The t-test showed a significant post-test difference between groups, $t(68) = -10.152$, $p < 0.001$. These findings indicate that PBL supports stronger cognitive achievement in orthogonal projection learning by engaging students in investigation, discussion, presentation, and evaluation. The findings directly recommend PBL for visual technical topics in vocational classrooms.

Keywords: Machining Engineering; Orthogonal Projection; Problem-Based Learning; Technical Drawing; Vocational Education

1. Introduction

Vocational high schools play an important role in preparing students with occupational knowledge, technical skills, work attitudes, and readiness for industry-based tasks (Imran et al., 2024; Inderanata & Sukardi, 2023; Swaramarinda et al., 2025). In the Indonesian vocational education context, learning is expected to connect classroom knowledge with practical competence so that students can meet the needs of industry and further technical training (Bruri Triyono & Hariyanto, 2024; S. Rahmawati et al., 2025; Suharno et al., 2020). This expectation is also aligned with the Merdeka Curriculum, which requires learning activities to support competency achievement, student characteristics, and contextual learning needs at each educational phase (Koko Adya Winata et al., 2026; Meidawati & Kusdarini, 2025). Therefore, vocational learning should not only deliver theoretical content, but also help students observe, analyse, discuss, and apply concepts in practical technical contexts.

Technical Drawing is an important subject in Machining Engineering because it functions as a visual language for communicating the shape, dimensions, symbols, views, and technical specifications of a component (Hirst & Whipp, 1989; Mackiewicz, 2025; Ushno, 2025). This competence is needed to understand work drawings used in machining, assembly, inspection, and mechanical maintenance, where visual information must be interpreted accurately to prevent errors in planning and production (Picard et al., 2025; Setiyawan et al., 2025). One essential topic in Technical Drawing is orthogonal projection, which requires students to connect three-dimensional objects with two-dimensional front, top, and side views. This process is often difficult because students must visualize object forms, determine viewing directions, and identify relationships across projected views, while weak spatial visual ability can make students struggle to analyse, understand, and read technical drawings (Contreras et al., 2018; Darwish et al., 2023; Y. Rahmawati et al., 2021).

A preliminary observation was conducted from 1 September to 1 October 2025 in Class X TPM 1 at SMK Negeri 5 Padang. The observation showed that students' achievement in Technical Drawing was still below the expected standard. This condition can be seen from the daily test results presented in Table 1.

Table 1. Preliminary observation results of students' daily test scores in technical drawing

No	Score range	Description	Number of students	Percentage
1	0–74	Below the minimum mastery criterion	20	57.10%
2	75–84	Met the minimum mastery criterion	10	28.60%
3	85–90	Met the criterion with high achievement	5	14.30%
		Total	35	100%

As shown in Table 1, 20 out of 35 students, or 57.10%, had not reached the minimum mastery criterion of 75. Only 10 students, or 28.60%, reached the score range of 75–84, while five students, or 14.30%, reached the higher score range of 85–90. These results indicate that most students had not yet achieved the expected level of mastery in Technical Drawing. Classroom observation also showed that several students lacked focus during instruction, relied heavily on teacher explanation, had low reading initiative, and were less confident in asking questions or explaining their answers. These problems suggest that conventional instruction may not be sufficient for teaching orthogonal projection. In the observed class, learning was mostly conducted through teacher explanation, examples, limited questioning, and exercises. This pattern helped students receive information, but it provided limited opportunities for them to investigate drawing problems, compare interpretations, discuss errors, and justify their reasoning (Alashwal & Barham, 2025; Oz & Isik, 2024). In Technical Drawing learning, teacher-centred instruction made students less active, less attentive, and more likely to experience difficulty in understanding the material (Trajkovski et al., 2025; Woods & Copur-Gencturk, 2024). Since Technical Drawing requires visual and conceptual understanding, the learning process should involve active problem analysis rather than one-way explanation.

Problem-Based Learning (PBL) is relevant for addressing this condition because it places problems at the centre of Learning (Bendeliani & Torstensdotter, 2026; Nicholus et al., 2023; Noordegraaf-Eelens et al., 2019). Through PBL, students are encouraged to identify information, examine learning resources, discuss possible solutions, present their work, and evaluate the problem-solving process. In engineering education, PBL is widely used because it reflects the nature of technical work, which requires problem-solving, knowledge application, reasoning, and responsibility for the process(Abugri et al., 2026; Funa, 2026; Lavado-Anguera et al., 2024). For Technical Drawing, PBL can provide a learning structure that allows students to connect visual objects with drawing concepts through investigation and discussion.

PBL has been found to support students' engagement and achievement in engineering-related learning by encouraging them to analyze problems, apply concepts, and take an active role in the learning process (J. Chen et al., 2021; Funa, 2026; Marini et al., 2026). In Engineering Drawing, PBL can improve student engagement, visualization, drawing skills, and learning outcomes (Alrefaie et al., 2026; Ingale, 2023). Similar findings were also reported in Technical Drawing learning for Grade X Machining Engineering students, where PBL improved learning outcomes (Barbosa et al., 2022; Mursid et al., 2022). However, existing studies tend to treat PBL as a complete learning model and give limited attention to how the guiding investigation stage supports students in reading orthogonal projection drawings (Sánchez-García & Reyes-de-Cózar, 2025; Q. Zhang & Lin, 2026). This creates a research gap, especially in explaining how students engage with objects, identify views, compare answers, and revise their understanding during orthogonal projection learning. The novelty of this study lies in its specific focus on implementing PBL in orthogonal projection learning, with attention to the guiding investigation stage as the most visible phase of student engagement.

This study does not claim that a single PBL syntax leads to improved learning. Instead, it examines the effect of PBL as a comprehensive learning model, describing how guided investigation supports students in analysing three-dimensional objects and translating them into two-dimensional technical views. This focus is important because orthogonal projection requires visualization, accuracy, and reasoning, which can be strengthened through active investigation. Based on this background, the study addresses the following research questions:

RQ1. How is Problem-Based Learning implemented in Technical Drawing instruction on orthogonal projection for Grade X Machining Engineering students at SMK Negeri 5 Padang?
RQ2. Is there a significant difference in cognitive learning outcomes on orthogonal projection between students taught using Problem-Based Learning and students taught using conventional instruction?

This study contributes to vocational and technical education in three ways. First, it provides empirical evidence on the use of PBL in Technical Drawing, particularly in the learning of orthogonal projection. Second, it explains how the guiding investigation stage creates opportunities for students to observe objects, search for information, discuss visual interpretations, and recheck their answers. Third, it offers practical insights for vocational teachers seeking a more active, context-based learning model to improve students' understanding of technical drawing concepts.

2. Methods

2.1 Research design

This study used a quantitative, quasi-experimental design (Campbell & Stanley, 1963; Rogers & Révész, 2019). This design was selected because the study aimed to examine the effect of Problem-Based Learning on students' Technical Drawing achievement through numerical data and statistical testing. A quasi-experimental design was appropriate because the researcher used existing school classes and could not randomly assign individual students to the experimental and control groups. This condition is common in classroom-based educational research, where researchers often compare intact groups rather than fully randomized participants (Wen, 2021). The study applied a non-equivalent control group design involving one experimental class and one control class. Both groups completed a pretest before the learning intervention and a post-test after the intervention. The experimental class was taught using Problem-Based Learning, while the control class was taught using conventional instruction. The structure of the research design is presented in Table 2.

Table 2. Research design

Group	Pretest	Treatment	Post-test
Experimental class	O_1	Problem-Based Learning	O_2
Control class	O_3	Conventional instruction	O_4

Note: O_1 and O_3 = pretest scores; O_2 and O_4 = post-test scores.

2.2 Research setting and participants

The study was conducted at SMK Negeri 5 Padang, West Sumatra, Indonesia. The research was conducted from 18 May to 8 June 2026 across three learning meetings. The population consisted of 104 Grade X Machining Engineering students in the 2025/2026 academic year. The students were distributed across three classes, namely X TPM 1, X TPM 2, and X TPM 3. Cluster random sampling was used because the population was already organized into intact classroom groups. This technique is suitable when sampling is conducted by class or cluster rather than by individual students (Ballance, 2024; Bulus, 2021). Class X TPM 1 was assigned as the experimental class, Class X TPM 2 was assigned as the control class, and Class X TPM 3 was used for instrument try-out. The distribution of the population and sample is shown in Table 3.

Table 3. Population and sample distribution

Class	Number of students	Role in the study
X TPM 1	35	Experimental class
X TPM 2	35	Control class
X TPM 3	34	Instrument try-out class
Total	104	

2.3 Treatment procedure

The experimental class received instruction using Problem-Based Learning. The learning process followed the main PBL stages, namely problem orientation, student organization, guided investigation, presentation of results, and evaluation of the problem-solving process. The learning material focused on orthogonal projection in Technical Drawing. During the guided investigation stage, students analysed drawing problems, identified front, top, and side views, discussed possible answers, and rechecked the consistency of their interpretations. The teacher supported students by guiding them with questions without directly providing final answers. The control class received conventional instruction, which consisted of teacher explanation, worked examples, limited question-and-answer activities, and individual exercises. Both classes studied the same Technical Drawing topic, received the same pretest and post-test, and followed the same research schedule.

2.4 Research instruments

The main instrument was a multiple-choice achievement test on orthogonal projection. The test was used to measure students' cognitive learning outcomes in Technical Drawing. The initial instrument consisted of 30 items developed based on the learning indicators. The indicators covered the basic concept of orthogonal projection, its function in technical drawing, European and

American projection systems, view layout, reading orthogonal projection drawings, and applying orthogonal projection in technical drawing.

Before the instrument was used in the main study, it was tested in Class X TPM 3. The item analysis included validity, reliability, difficulty level, and discrimination power. Item validity was tested using a biserial correlation because the test used dichotomous scoring, with 1 for correct answers and 0 for incorrect answers (Attali & Fraenkel, 2000). Reliability was calculated using the Kuder-Richardson 20 formula because the instrument consisted of multiple-choice items with dichotomous scores. Item difficulty and discrimination power were also examined to determine whether each item was appropriate for measuring student achievement (Ntumi et al., 2023). The instrument try-out results are summarized in Table 4.

Table 4. Summary of Instrument Quality

Aspect	Result	Interpretation
Initial number of items	30	Tested in the try-out class
Valid items	28	Used in the main study
Removed items	2	Not used in the main study
KR-20 reliability	0.914	Very high reliability
Difficulty level	6 difficult, 14 moderate, 10 easy	Varied item difficulty
Discrimination power	8 sufficient, 16 good, 4 very good	Most items had acceptable discrimination

As presented in Table 4, 28 of the 30 test items met the validity and discrimination criteria and were therefore used in the main data collection. The KR-20 reliability coefficient of 0.914 indicates that the test had very high internal consistency. This result shows that the instrument was reliable and appropriate for measuring students' Technical Drawing achievement.

2.5 Data collection

Data were collected through achievement tests and documentation. The pretest was given to both classes before instruction to identify students' initial ability in orthogonal projection. After the learning process, both classes completed the post-test to measure learning achievement after treatment. Documentation was used as supporting data to record the research setting, class activities, student lists, and the implementation of learning. However, documentation was not treated as quantitative evidence of student engagement. The main quantitative data analysed in this study were the pretest and post-test scores obtained from the experimental and control classes.

2.6 Data analysis

The data were analysed using descriptive and inferential statistics. Descriptive statistics were used to report the minimum, maximum, mean, and standard deviation of pretest and post-test scores in both classes. This analysis provided an overview of students' learning outcomes before and after treatment. Before hypothesis testing, the data were tested for normality and homogeneity. The Shapiro-Wilk test was used to assess whether the data were normally distributed (Shapiro & Wilk, 1965). The Levene test was used to examine the homogeneity of variance between the experimental and control groups (Y.-H. Chen et al., 2018). The decision rule was based on a significance level of 0.05. Data were considered normal or homogeneous when the significance value was greater than 0.05.

After the assumptions of normality and homogeneity were met, the post-test scores of the experimental and control classes were compared using an independent samples t-test. This test was used to determine whether there was a significant difference in Technical Drawing achievement between students taught using Problem-Based Learning and students taught using conventional instruction. The null hypothesis was rejected when the significance value was less than 0.05. The t-test was selected because it is appropriate for comparing the mean scores of two independent groups (Palmer et al., 2022). All statistical analyses were conducted using IBM SPSS Statistics.

3. Results and discussion

3.1 Implementation of problem-based learning in the experimental class

The learning process was conducted in three meetings for both the experimental and control classes. The experimental class, X TPM 1, learned orthogonal projection through Problem-Based Learning, while the control class, X TPM 2, followed conventional instruction. Each class consisted of 35 students. In the first meeting, both classes completed a pretest to identify their initial ability. The experimental class was then introduced to a problem related to object viewing directions, while the control class received teacher explanation, examples, and guided questioning. In the second meeting, the experimental class worked in groups to analyse object forms, determine front, top, and side views, and construct orthogonal projection drawings. The control class continued with explanation, examples, and exercises. In the third meeting, both classes completed a post-test. The implementation of Problem-Based Learning in the experimental class followed five main stages. The learning activities are summarised in Table 5.

Table 5. Implementation of problem-based learning in the experimental class

Meeting	PBL stage	Main teacher activities	Main student activities
1	Problem orientation	Introduced the learning objectives and presented an object or simple drawing problem related to viewing directions.	Observed the object, identified its form, and recorded information related to front, top, and side views.
1	Organizing students for learning	Formed small groups, explained group tasks, and distributed worksheets.	Joined groups, divided roles, read task instructions, and discussed possible viewing directions.
2	Guiding individual and group investigation	Guided students, divided roles, read task instructions, and discussed possible ways of observing object forms; monitored group discussion, and asked guiding questions when students had difficulty.	Analysed object shapes, determined front, top, and side views, searched for information, and compared group ideas.
2	Developing and presenting work	Directed students to convert their analysis into orthogonal projection drawings and present selected group results.	Created projection drawings, checked line accuracy and view layout, and explained their reasoning.
3	Analysing and evaluating problem solving	Reviewed group work, corrected errors, reinforced concepts, and guided students to conclude the lesson.	Compared results, responded to feedback, corrected mistakes, drew conclusions, and completed the post-test.

As shown in Table 5, student engagement was most visible during the investigation, presentation, and evaluation stages. During these stages, students not only received information from the teacher but also observed objects, discussed visual interpretations, determined projection views, presented their drawings, and corrected errors. This pattern indicates that PBL created a more active, context-based learning process for understanding the relationship between three-dimensional objects and two-dimensional technical drawings.

3.2 Descriptive results of students' learning outcomes

Students' learning outcomes were measured through pretest and post-test scores. The descriptive statistics of both classes are presented in Table 6.

Table 6. **Descriptive** statistics of pretest and posttest scores

Group	Test	N	Minimum	Maximum	Mean	Standard Deviation	Variance
Control	Pretest	35	35.71	67.86	53.67	7.32	53.56
Control	Post-test	35	50	78.57	64.29	6.39	40.83
Experimental	Pretest	35	39.29	71.43	53.57	8.75	76.52
Experimental	Post-test	35	67.86	92.86	79.28	5.78	33.37

Table 6 shows that the initial ability of both groups was relatively similar. The experimental class had a pretest mean of 53.57, while the control class had a pretest mean of 53.67. The difference of only 0.10 points indicates that both groups had almost equal initial ability before treatment. After instruction, both groups improved, but the increase was higher in the experimental class. The experimental class improved by 25.71 points, from 53.57 to 79.28, while the control class improved by 10.62 points, from 53.67 to 64.29. The post-test standard deviation of the experimental class also decreased from 8.75 to 5.78, showing that students' scores became more concentrated after learning through PBL.

3.3 Assumption testing and hypothesis testing

Before conducting hypothesis testing, the data were tested for normality and homogeneity. The Shapiro-Wilk test was used for normality, while Levene's test was used for homogeneity of variance. The results are presented in Table 7.

Table 7. **Results** of assumption testing and independent samples t-test

Test	Data	Statistic / Value	df	Sig.	Interpretation
Shapiro-Wilk	Experimental pretest	0.956	35	0.176	Normal
Shapiro-Wilk	Experimental post-test	0.95	35	0.117	Normal
Shapiro-Wilk	Control pretest	0.971	35	0.472	Normal
Shapiro-Wilk	Control post-test	0.975	35	0.603	Normal
Levene's test	Post-test scores	0.312	1, 68	0.579	Homogeneous
Independent samples t-test	Post-test scores	-10.152	68	< 0.001	Significant difference

The normality results indicate that all p-values were greater than 0.05. Therefore, the pretest and post-test scores in both groups were normally distributed. The Levene's test also showed a p-value of 0.579, which was greater than 0.05. This means that the post-test variances of both groups were homogeneous and suitable for parametric testing. The Normal Q-Q plots in Figure 1 also support the normality pattern.

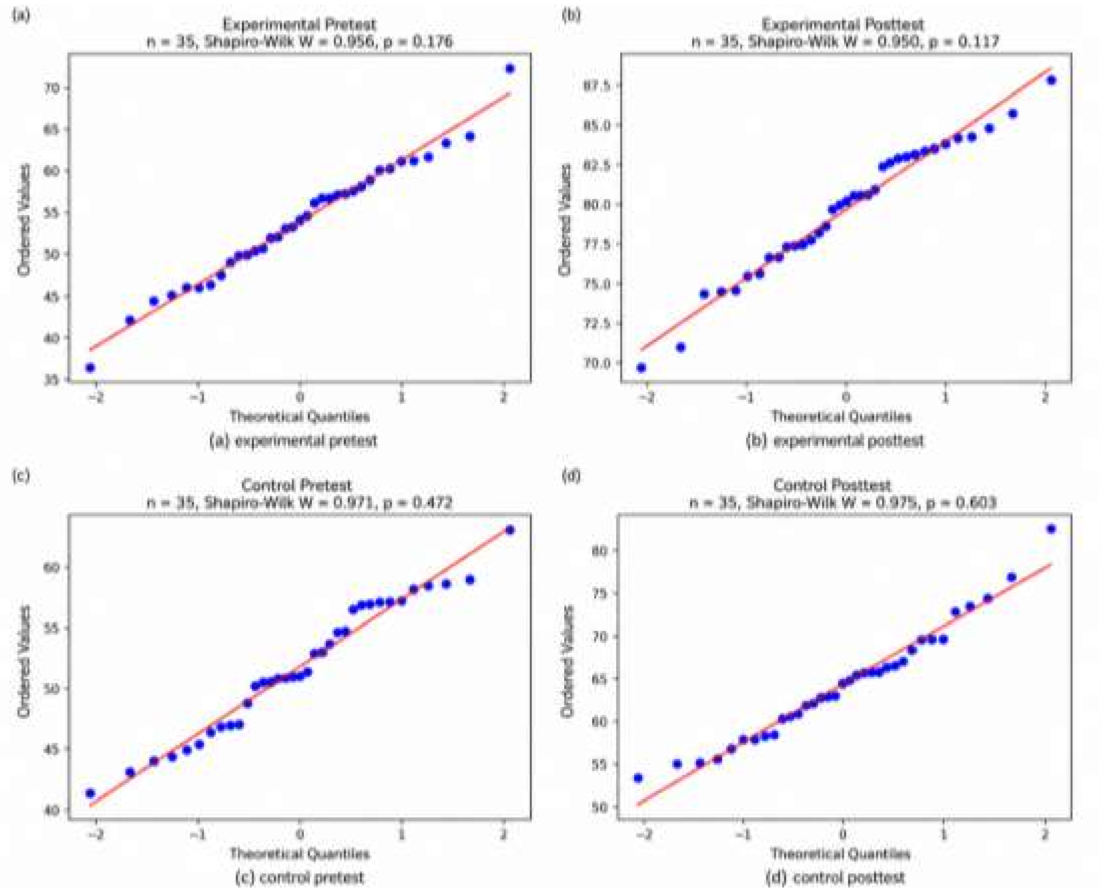

Figure 1. Normal Q-Q plots of the pretest and post-test scores in the experimental and control classes. Note. Panel (a) shows the experimental pretest, panel (b) shows the experimental posttest, panel (c) shows the control pretest, and panel (d) shows the control post-test.

Figure 1 presents the Normal Q-Q plots for the experimental pretest, experimental post-test, control pretest, and control post-test scores. The data points in all four plots are generally positioned close to the diagonal reference line. Only minor deviations appear at the lower and upper ends of the distributions. This pattern indicates that the score distributions in both classes were approximately normal. The visual evidence from the Q-Q plots supports the Shapiro-Wilk test results presented in Table 4. All significance values were greater than 0.05, including the experimental pretest (p = 0.176), experimental post-test (p = 0.117), control pretest (p = 0.472), and control post-test (p = 0.603). Therefore, the normality assumption was met, and the data were appropriate for further analysis using an independent-samples t-test. This supports the validity of comparing post-test scores between the Problem-Based Learning class and the conventional instruction class.

4. Discussion

The findings show that Problem-Based Learning had a positive effect on students' learning outcomes in Technical Drawing, particularly on orthogonal projection material. The higher achievement in the experimental class was closely related to the learning process. Students were not only asked to listen to explanations, but also to observe objects, discuss possible answers, analyze views, create projection drawings, present group work, and correct errors. This learning structure allowed students to build understanding through investigation and problem solving. The guiding investigation stage was the most important stage for orthogonal projection learning. At this stage, students analyzed object forms, identified front, top, and side views, searched for supporting information, and compared their answers with group members. These activities were directly related to the main difficulty in orthogonal projection: connecting three-dimensional objects to their two-dimensional views. Through guided investigation, students could examine the relationship between object form, viewing direction, and projection layout more concretely.

The results are consistent with the basic principle of Problem-Based Learning, which places students at the centre of the learning process while the teacher acts as a facilitator (Wang, 2021; Yew & Goh, 2016). In this study, the teacher guided students through questions and corrections rather than giving direct answers. This helped students become more active in analyzing problems and checking the accuracy of their drawings. The finding also supports the view that PBL can encourage students to become more active, independent, critical, and collaborative in solving learning problems (Widiastuti et al., 2023; L. Zhang & Ma, 2023). The difference between the experimental and control classes also highlights the limitations of conventional instruction in teaching orthogonal projection. Conventional learning still improved students' scores, but the improvement was smaller because students mainly listened to explanations, followed examples, and completed exercises (Hattie & O'Leary, 2025; Tong et al., 2022). This approach gave fewer opportunities for students to explore object forms, discuss alternative interpretations, and evaluate projection errors. In contrast, PBL provided a more active learning pathway that connected visual analysis, group discussion, drawing practice, and evaluation.

Previous studies in technical and vocational learning also support these findings. Problem-Based Learning can help students understand technical problems through systematic thinking processes (Marini et al., 2026). In Technical Drawing, PBL has been reported to improve learning outcomes in projection material and Grade X Machining Engineering learning (Adli, 2023; Gomez-del Rio & Rodriguez, 2022). Similar findings were also reported in visual and technical subjects, where PBL supported students' understanding, visualization, and problem-solving skills (Alrefaie et al., 2026). Overall, the results indicate that implementing Problem-Based Learning created a more active, collaborative, and student-centred learning environment. The model helped students understand orthogonal projection more concretely by involving them in problem orientation, group investigation, drawing production, presentation, and evaluation. However, the improvement in learning outcomes should be interpreted as the effect of the complete PBL sequence, not as the isolated effect of one syntax. The guiding investigation stage can be understood as the stage where student engagement was most visible, but the learning gains resulted from the integrated implementation of all PBL stages.

5. Implications and limitations of the study

The findings imply that Problem-Based Learning can be used as a practical instructional model for Technical Drawing, especially for material on orthogonal projection. The model helped students move beyond passive listening by having them observe objects, identify front, top, and side views, discuss interpretations, present drawings, and correct errors. The higher posttest mean in the experimental class (53.57-79.28) compared with the control class (53.67-64.29) indicates that PBL supported stronger cognitive learning outcomes than conventional instruction. For vocational teachers, this means that orthogonal projection should be taught through active visual investigation, guided questioning, and group discussion, rather than solely through explanation and drawing exercises. This study has several limitations. First, the research used a quasi-experimental design with intact classes, so individual randomization was not possible. Second, the study was conducted at one school, involved only Grade X Machining Engineering students, and lasted three meetings, limiting generalizability to other vocational contexts. Third, the outcome measurement focused on cognitive achievement through a multiple-choice test, while spatial ability, drawing performance, student engagement, and long-term retention were not measured directly. Documentation was used only as supporting evidence and not as a quantitative measure of student activity. Therefore, the findings should be interpreted as the effect of the full PBL sequence, not as the isolated effect of the guiding investigation stage.

6. Conclusion

This study concludes that implementing Problem-Based Learning improved students' learning outcomes in Technical Drawing, particularly in orthogonal projection material. The experimental class achieved a higher posttest score than the control class, and the independent-samples t-test showed a significant difference between the groups. The learning process also showed that students were most actively involved during the guiding investigation stage, where they observed object forms, determined projection views, compared answers, and revised their understanding. However, the improvement in learning outcomes should be understood as the result of the complete PBL process, including problem orientation, group organization, guided investigation, presentation, and evaluation. Based on these findings, Technical Drawing teachers are recommended to apply PBL when teaching topics that require visualization, reasoning, and interpretation of technical objects. Teachers should prepare clear drawing problems, structured worksheets, guiding questions, and opportunities for students to discuss and present their work. Future research should involve more schools, longer interventions, and larger samples. Further studies should also measure spatial visual ability, practical drawing performance, student engagement, and retention. In addition, future researchers may compare different PBL stages or combine PBL with visual media, 3D models, or augmented reality to strengthen students' understanding of orthogonal projection.

Author's declaration

Author contribution

Aprilia Eka Salwa contributed to conceptualization, data collection, data analysis, and original manuscript drafting. **Syahril** contributed to supervision, research direction, and manuscript review. **Eko Indrawan** contributed to supervision, review, and final manuscript improvement. All authors read and approved the final manuscript. **Gulzhaina K. Kassymova** contributed to methodology validation, academic input, and manuscript revision.

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Conflict of interest

The authors declare no conflict of interest.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical clearance

Permission to conduct this study was granted by the Department of Education of West Sumatra Province under approval letter No. 000.9/4500/PSMK/DISDIK-2026. The research was carried out in accordance with established ethical principles for educational research, including respect for participants' rights, voluntary participation, informed consent, confidentiality, and data privacy. Furthermore, the study adhered to the ethical principles outlined in the *Declaration of Helsinki* for research involving human participants.

AI statement

AI-assisted tools were used only to support language refinement and editing. The authors reviewed, verified, and take full responsibility for the content, data analysis, interpretation, and final manuscript.

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