J-EDU: Jurnal Pendidikan dan Kesehatan
E-ISSN: 2776-5857 | P-ISSN: 2776-7876
Website: https://j-edu.org/index.php/

VOLUME 4, ISSUE 1, 2026

PROJECT-BASED LEARNING AND THE CONSISTENCY OF DIAL-INDICATOR COMPETENCY GAINS IN AUTOMOTIVE VOCATIONAL EDUCATION: A QUASI-EXPERIMENTAL PRETEST-POSTTEST STUDY

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ABSTRAK

Pengukuran presisi menuntut siswa vokasi otomotif mengintegrasikan pengetahuan konseptual dengan ketepatan pemasangan instrumen, pembacaan, interpretasi, dan kendali prosedural. Studi kuasi-eksperimental pretest-posttest ini menilai apakah Project-Based Learning (PjBL) berkaitan dengan peningkatan kompetensi dial indicator yang lebih besar dan lebih konsisten pada siswa kelas X. Enam puluh empat siswa dari dua kelas utuh Teknik Kendaraan Ringan berpartisipasi (32 PjBL; 32 kontrol). Kemampuan awal setara (46,41 ± 7,21 vs 46,56 ± 7,01; p = 0,930). Kedua kelompok meningkat substansial. Rata-rata peningkatan sebesar 42,19 ± 4,00 pada PjBL dan 39,22 ± 11,99 pada kontrol; keunggulan 2,97 poin tidak signifikan secara statistik (Welch p = 0,192; Hedges' g = 0,33). Dispersi peningkatan berbeda nyata: varians kelompok kontrol 8,97 kali varians PjBL, dengan uji varians robust p < 0,001. Dengan demikian, PjBL lebih jelas berkaitan dengan konsistensi perkembangan kompetensi daripada keunggulan peningkatan rata-rata. Replikasi multikelas dengan asesmen kinerja tervalidasi diperlukan.

Kata Kunci: *Project-Based Learning; pendidikan vokasi otomotif; dial indicator; pengukuran presisi; pengembangan kompetensi*

ABSTRACT

Precision measurement requires automotive vocational students to integrate conceptual knowledge with accurate instrument setup, reading, interpretation, and procedural control. This quasi-experimental pretest-posttest study examined whether Project-Based Learning (PjBL) was associated with larger and more consistent gains in Grade X students' dial-indicator competency. Sixty-four students from two intact Light Vehicle Engineering classes participated (32 PjBL; 32 control). Baseline performance was equivalent (46.41 ± 7.21 vs 46.56 ± 7.01; p = .930). Both groups improved substantially. Mean gain was 42.19 ± 4.00 under PjBL and 39.22 ± 11.99 in the control group; the 2.97-point advantage was not statistically significant (Welch p = .192; Hedges' g = .33). Gain dispersion differed markedly: control-group variance was 8.97 times the PjBL variance, with robust variance tests p < .001. PjBL was therefore associated more clearly with consistency of competency development than with superior average gain. Multiclass replication with validated performance assessment is warranted.

***Keywords:** Project-Based Learning; automotive vocational education; dial indicator; precision measurement; competency development*

INTRODUCTION

Vocational education is judged not only by what students know but by what they can perform reliably under conditions that approximate occupational practice. This distinction is particularly important in technical programs, where competence depends on integrating conceptual understanding with procedural execution, tool handling, problem solving, and the ability to verify one's own work. Recent vocational-education research consistently emphasizes the need to connect theory with authentic practice, because practical involvement can strengthen deeper learning and work-oriented competence (Dzulkurnain et al., 2024; Prianto & Qomariyah, 2022). In Indonesian and international technical-education contexts, hands-on and student-centered approaches are likewise positioned as mechanisms for narrowing the gap between classroom knowledge and industry requirements (Nurahman et al., 2025; Prasanthi Kumari & Suresh Kumar, 2020; Sukis et al., 2026). For students in Light Vehicle Engineering, this integration is especially consequential because workshop performance requires technical accuracy as well as disciplined procedural habits.

The dial indicator provides a focused context for examining this challenge. It is a precision-comparison instrument used to observe small dimensional deviations, run-out, end play, alignment, or relative movement. Competent use is not reducible to memorizing scale divisions. A learner must mount and stabilize the instrument, orient the contact point, establish an appropriate reference and preload, observe displacement, interpret pointer movement, and connect the reading to the diagnostic purpose of the task. Because these operations are sequential and interdependent, an early setup error can propagate into the final result. Dial-indicator competency therefore represents the type of integrated technical performance for which vocational pedagogy should connect knowledge, action, feedback, and verification rather than treat conceptual and psychomotor components as separate learning targets.

Project-Based Learning (PjBL) is well aligned with this requirement because it organizes learning around a purposeful problem, product, or performance goal rather than a sequence of isolated explanations. Bibliometric evidence shows that PjBL has become an increasingly prominent strand of vocational-education research (Ahmad et al., 2023), while studies in technical and vocational settings describe project work as a vehicle for linking theoretical knowledge with authentic practice, learner autonomy, and industry-relevant experience (Ali et al., 2025; Green & du Plessis, 2023; Hamdani & Suherman, 2021). In engineering education, project structures also provide opportunities to integrate technical and socio-emotional learning through real problem solving (Mukunda Vani et al., 2021). Research in natural or workplace-like contexts similarly associates project activity with stronger perceptions of professional competence (Pla-Campas et al., 2025). These findings support a plausible pedagogical rationale for using PjBL in precision measurement: students can repeatedly execute a complete measurement workflow in a meaningful technical context rather than encounter the instrument only as a decontextualized demonstration.

Empirical studies across vocational domains generally support the capacity of project-oriented instruction to improve learning outcomes, although effect sizes, implementation models, and outcome definitions vary. Quasi-experimental work has reported advantages for PjBL or PjBL-enhanced approaches in technical drawing, welding, computer networking, graphic design, multilevel turning, and broader vocational competence (Handoyono & Johan, 2020; Hidayat et al., 2026; Huda et al., 2026; Rahim et al., 2024). Developmental and experimental studies also report positive competence-related outcomes when projects are integrated with mobile learning or authentic technical tasks (Astudillo & Illescas, 2025; Setiawan et al., 2020). Other vocational studies extend these benefits to critical thinking, metacognition, and 4C-related skills (Maknun & Herman, 2024; Ramdhayani & Purwoko, 2023; Wulansari et al., 2022). Collectively, this literature suggests that PjBL can support competence formation, but it also indicates that "PjBL" is not a single standardized treatment and that outcomes depend on how projects, scaffolding, resources, and assessment are designed.

That implementation dependence is important for interpreting evidence. Reviews of PjBL frameworks show substantial variation in the nature of problems, team structures, scaffolding, student engagement, and assessment arrangements (Kaushik & Joshi, 2020). A recent systematic review of applied-science PjBL similarly identified multiple design variants together with recurring implementation constraints related to time, learner readiness, teacher readiness, industry collaboration, and resource support (Sidik et al., 2026). In vocational secondary schools, sustained implementation has also been linked to leadership, collaborative culture, professional development, and organizational conditions (González et al., 2026), while broader reviews emphasize that teacher roles, student roles, equipment, and learning environments can limit effectiveness (Megayanti et al., 2020). Thus, positive average effects reported elsewhere should not be assumed automatically for a specific technical competency or classroom context.

A second issue concerns what is meant by "effective." Most classroom evaluations privilege average post-test scores or average gains. Yet a class mean can improve while individual learning trajectories remain highly uneven. This distinction matters in competency-based vocational education, where a foundational procedure may need to be performed dependably by every learner. Evidence from vocational settings shows that learner readiness and perceived usefulness of teaching resources can be heterogeneous (Bascuguin & Generoso, 2026; Canut-Montalva et al., 2025). Conversely, a quasi-experimental study of vlog-integrated PjBL in culinary education reported not only improved practicum outcomes but also a more consistent distribution of performance across ability levels (Asnur et al., 2025). These observations suggest that dispersion itself can carry pedagogical information: two instructional conditions may produce similar means while differing substantially in how reliably they move individual learners forward.

This consideration defines the research gap addressed here. Bibliometric syntheses show continued growth of PjBL in vocational education and identify automotive and machinery among its application areas, but they also call for more context-specific comparative evidence (Ibrahim, 2025; Muhtar, Suryanti, Bachri, Mila, et al., 2025). Within the literature reviewed for this study, automotive-oriented PjBL research has focused on areas such as vehicle-body technology and chassis troubleshooting (Hasan et al., 2026; Wakid et al., 2020), while a recent study involving Grade X Automotive Light Vehicle Technology students examined a contextual science project module rather than precision-measurement performance (Anwar et al., 2026). None of the supplied studies directly evaluates dial-indicator competency, and none treats between-student variability in gain as a primary outcome. The present study therefore narrows the unit of analysis to a specific precision-measurement competency and broadens the definition of instructional effectiveness from mean improvement alone to both the magnitude and the consistency of individual learning gains.

Two hypotheses guided the analysis. The first hypothesis (H1) was that students in the PjBL group would exhibit larger competency gains than students in the control group. The second hypothesis (H2) was that competency gains under PjBL would be less variable across students, indicating more consistent progression. H2 does not substitute for H1; it addresses a different property of instructional performance. The study consequently asks: to what extent is PjBL associated with the magnitude and consistency of gains in students' dial-indicator competency in automotive vocational education? By separating central tendency from dispersion, the analysis seeks to determine whether project-oriented instruction offers an advantage in average achievement, reliability of competency development, or both.

METHODS

2.1 Study design and analytical sample

The study dataset was analyzed as a two-group pretest-posttest quasi-experimental dataset. The term quasi-experimental is used conservatively because the data identify intact classes and treatment labels but do not document individual random allocation. The analytical sample comprised 64 students: 32 students in class X TKR 2, labeled "Eksperimen," and 32 students in class X TKR 4, labeled "Kontrol." The course was PDTO (Pekerjaan Dasar Otomotif), the instructional material was "Dial Indikator," and the learning model recorded for the experimental condition was Project Based Learning. Every listed student had a pre-test and a post-test score, so no case was removed for missing outcome data.

The unit of analysis was the individual student. Each student contributed one baseline observation and one post-instruction observation. The two classes were treated as independent groups, while repeated measurements within a student were treated as paired observations. Because the dataset contains only one experimental class and one control class, the group contrast is also inseparable from the class contrast. Accordingly, statistical inference in this draft is directed at the observed classes and is not interpreted as a cluster-randomized estimate. This distinction is important because teacher effects, classroom climate, scheduling, peer composition, or other class-level factors could contribute to group differences if they were not controlled by the original study design.

2.2 Instructional condition and competency outcome

The experimental condition was recorded as Project-Based Learning in the study dataset. In conceptual terms, PjBL was treated as an instructional approach in which learning is organized around a purposeful task or project requiring the application of knowledge and practical procedures. For dial-indicator learning, the pedagogically relevant features would include integrated task execution, repeated tool use, planning, observation, verification, and correction. The study records, however, does not encode the duration of instruction, detailed project sequence, teacher actions, group organization, feedback schedule, or the precise instructional method used in the control class. These variables were therefore not reconstructed or assumed in the statistical analysis.

The outcome variable was the recorded competency score on a 0–100 scale. Pre-test score represented performance before the instructional period and post-test score represented performance after the instructional period. An individual gain score was calculated as post-test minus pre-test. Gain was selected as a transparent measure of within-student change because baseline scores were available for all students and were highly comparable between groups. No subscale scores were provided, so the outcome was analyzed as a composite score. The study records also did not provide a documented pass threshold, assessment rubric, reliability coefficient, or separate indicators of cognitive and psychomotor performance; therefore, the manuscript does not assign an official competency category to any score.

2.3 Statistical analysis

Analysis proceeded in five stages. First, score distributions were summarized using sample size, mean, standard deviation, median, interquartile range, minimum, maximum, and 95% confidence intervals for the mean. This combination was chosen because the scores were discrete and some distributions departed from normality; presenting both mean-based and rank-based summaries reduces dependence on a single distributional description. Baseline comparability was then examined using the difference in pre-test means and a Welch independent-samples t-test. Welch's test was preferred to the equal-variance Student t-test as a generally robust default when group variances may differ.

Second, within-group change was quantified by calculating individual gain scores and testing the mean pre-post difference using paired-samples t-tests. Because the experimental-group gain distribution was highly concentrated at a small set of values, Wilcoxon signed-rank tests were also used as sensitivity checks for the direction of within-group change. For the paired t-tests, 95% confidence intervals around the mean gain were calculated from the standard error of the paired differences. The standardized within-group change was described using Cohen's dz, defined as the mean paired difference divided by the standard deviation of the paired differences. These within-group effect sizes are interpreted as descriptive measures of the magnitude of change, not as causal treatment effects.

Third, the primary between-group comparison focused on individual gain. The mean gain difference was tested using Welch's independent-samples t-test and expressed with a 95% confidence interval. A Mann-Whitney U test was conducted as a rank-based sensitivity analysis because the PjBL gain distribution was non-normal and the gain variances were markedly different. Hedges' g was calculated from the pooled standard deviation as a small-sample corrected standardized mean difference. A parallel between-group comparison was performed for post-test scores to show whether the observed gain pattern translated into a difference in final achievement.

Fourth, consistency of learning gains was evaluated explicitly. This analysis examined the standard deviation, interquartile range, range, and variance ratio of gain scores. The Brown-Forsythe version of Levene's test, centered on the median, was used to test equality of gain variances because it is more robust than the classical variance-ratio test under non-normality. The Fligner-Killeen test provided an additional nonparametric check of dispersion. The variance ratio was calculated as the control-group gain variance divided by the PjBL-group gain variance; values greater than one indicate greater heterogeneity in the control group. This component was prespecified in the manuscript logic as central to H2.

Fifth, relationships between baseline and post-test performance were examined descriptively using Pearson and Spearman correlations within each group. These analyses were not used as substitute treatment-effect tests. Rather, they were used to characterize whether initial ranking among students was preserved after instruction and whether gain depended strongly on baseline score. A conventional analysis of covariance was not treated as the primary model because an exploratory pretest-by-group interaction indicated nonparallel baseline-post-test relationships across the two classes, undermining the homogeneity-of-regression-slopes assumption required for a simple common-slope ANCOVA. Direct analysis of change scores was therefore retained as the clearer comparison for this dataset.

2.4 Statistical decision rules and reproducibility

All hypothesis tests were two-sided unless the analysis represented a sensitivity check of the clearly positive pre-post direction. Statistical significance was evaluated at $\alpha = 0.05$, but interpretation was not based on p-values alone. Effect estimates, confidence intervals, standardized effects, distributional shape, and practical meaning were considered together. This is particularly important for a sample of 32 students per group, where a small-to-moderate mean difference may be estimated imprecisely even when its direction is stable. Conversely, a very small p-value for within-group change does not establish that PjBL is superior to the control condition, because both groups were exposed to instruction and both could improve.

Calculations were performed directly from the 64 student-level score pairs in the study dataset. The analysis retained the original integer scores and did not impute, transform, winsorize, or exclude observations. Figures were generated from the same student-level data. The analytical workflow is therefore fully traceable from the recorded pre-test and post-test values to the reported descriptive and inferential statistics.

RESULTS AND DISCUSSION

3.1 Results

3.1.1 Baseline comparability

The two groups began at almost the same level of measured competency. The PjBL group had a mean pre-test score of 46.41 (SD 7.21; 95% CI 43.81–49.01), while the control group had a mean of 46.56 (SD 7.01; 95% CI 44.04–49.09). The absolute difference was only 0.16 points in favor of the control group. Welch's t-test yielded $t = -0.09$, $df = 61.95$, $p = 0.930$, and Hedges' $g = -0.02$. The 95% confidence interval for the mean difference extended from -3.71 to 3.40 points. On the observed scale, there is therefore no indication of a meaningful baseline advantage for either class.

Distributional summaries reinforce this conclusion. Both groups had a pre-test median of 45. The PjBL interquartile range was 40–50 and the control interquartile range was 43.75–50. Scores ranged from 35 to 60 in the PjBL group and from 30 to 60 in the control group. Although the control group included one lower minimum, central tendency and overall dispersion were closely aligned. This near-equivalence is analytically valuable because the subsequent change comparison does not begin from a large mean imbalance that would mechanically favor one group.

3.1.2 Improvement within each group

Post-test performance increased sharply in both classes. In the PjBL group, the mean score rose from 46.41 to 88.59, corresponding to a mean gain of 42.19 points (SD 4.00; 95% CI 40.74–43.63). The paired-samples t-test produced $t(31) = 59.61$, $p < 0.001$. The standardized paired change was extremely large (Cohen's $d_z = 10.54$), reflecting not only the large upward shift but also the unusually small variability of individual gain scores. The Wilcoxon signed-rank sensitivity test likewise supported a positive change ($p < 0.001$). Every student in the PjBL group improved by at least 40 points, and the observed gain range was 40–60 points.

The control group also improved substantially. Its mean score increased from 46.56 to 85.78, with a mean gain of 39.22 points (SD 11.99; 95% CI 34.90–43.54). The paired-samples t-test yielded $t(31) = 18.51$, $p < 0.001$, and Cohen's $d_z = 3.27$. The Wilcoxon signed-rank sensitivity analysis again indicated a clear positive shift ($p < 0.001$). These results show that instruction in both classes was associated with major improvement. Consequently, the strong within-group significance in the PjBL class cannot by itself be interpreted as evidence that PjBL outperformed the control condition.

Figure 1 visualizes the movement in group means with 95% confidence intervals. The two trajectories begin from nearly the same baseline and rise steeply. The PjBL trajectory ends modestly above the control trajectory, but the confidence intervals around the post-test means overlap. The visual pattern is therefore consistent with a positive directional advantage for PjBL rather than a decisive separation in mean final performance.

Table 1. *Descriptive statistics for pre-test, post-test, and individual gain scores.*

Group	Measure	n	Mean (SD)	Median (IQR)	Range	95% CI of mean
PjBL	Pre-test	32	46.41 (7.21)	45.0 (40.0-50.0)	35-60	43.81-49.01
PjBL	Post-test	32	88.59 (8.54)	87.5 (83.75-95.0)	75-100	85.51-91.67
PjBL	Gain	32	42.19 (4.00)	40.0 (40.0-45.0)	40-60	40.74-43.63
Control	Pre-test	32	46.56 (7.01)	45.0 (43.75-50.0)	30-60	44.04-49.09
Control	Post-test	32	85.78 (8.14)	85.0 (80.0-95.0)	75-100	82.85-88.72
Control	Gain	32	39.22 (11.99)	40.0 (30.0-50.0)	20-65	34.90-43.54

Note. Gain = post-test minus pre-test; IQR = interquartile range; CI = confidence interval.

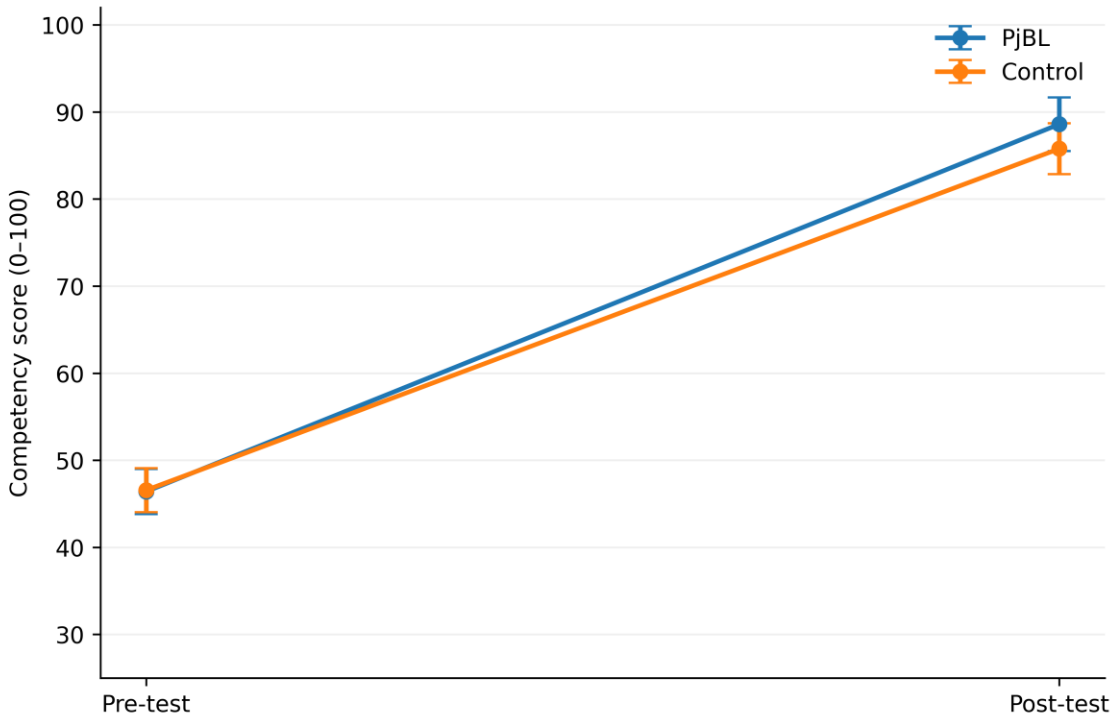

Fig. 1. Mean pre-test and post-test competency scores with 95% confidence intervals. Both groups improved markedly; the PjBL group showed a modestly higher post-test mean.

3.1.3 Between-group differences in post-test and gain

At post-test, the PjBL group achieved a mean score of 88.59 (SD 8.54; median 87.5) compared with 85.78 (SD 8.14; median 85.0) in the control group. The estimated mean difference was 2.81 points in favor of PjBL. Welch's t-test yielded t = 1.35, df = 61.86, p = 0.183. The 95% confidence interval for the difference ranged from -1.36 to 6.98 points, and Hedges' g was 0.33. A Mann-Whitney comparison of post-test distributions produced a similar non-significant conclusion (p = 0.177). Thus, the observed final-score advantage is small to moderate in standardized terms but remains statistically uncertain in this sample.

The analysis of gain scores produced a closely related result. The PjBL group improved by an average of 42.19 points, while the control group improved by 39.22 points. The between-group gain difference was 2.97 points. Welch's t-test yielded t = 1.33, df = 37.83, p = 0.192, with a 95% confidence interval from -1.56 to 7.49 points. Hedges' g for the gain difference was 0.33. The confidence interval includes zero, so H1 is not statistically confirmed at the conventional 0.05 level. At the same time, the point estimate consistently favors PjBL in both post-test and gain analyses.

The rank-based sensitivity test is informative because the gain distributions differ strongly in shape. The Mann-Whitney U statistic was 577.0, p = 0.370. The corresponding probability-of-superiority estimate was approximately 0.56, indicating only a modest tendency for a randomly selected PjBL student to have a larger gain than a randomly selected control student. This result further cautions against presenting the study as proof of a superior average treatment effect. The more distinctive pattern lies in the spread of gains, not in their central rank.

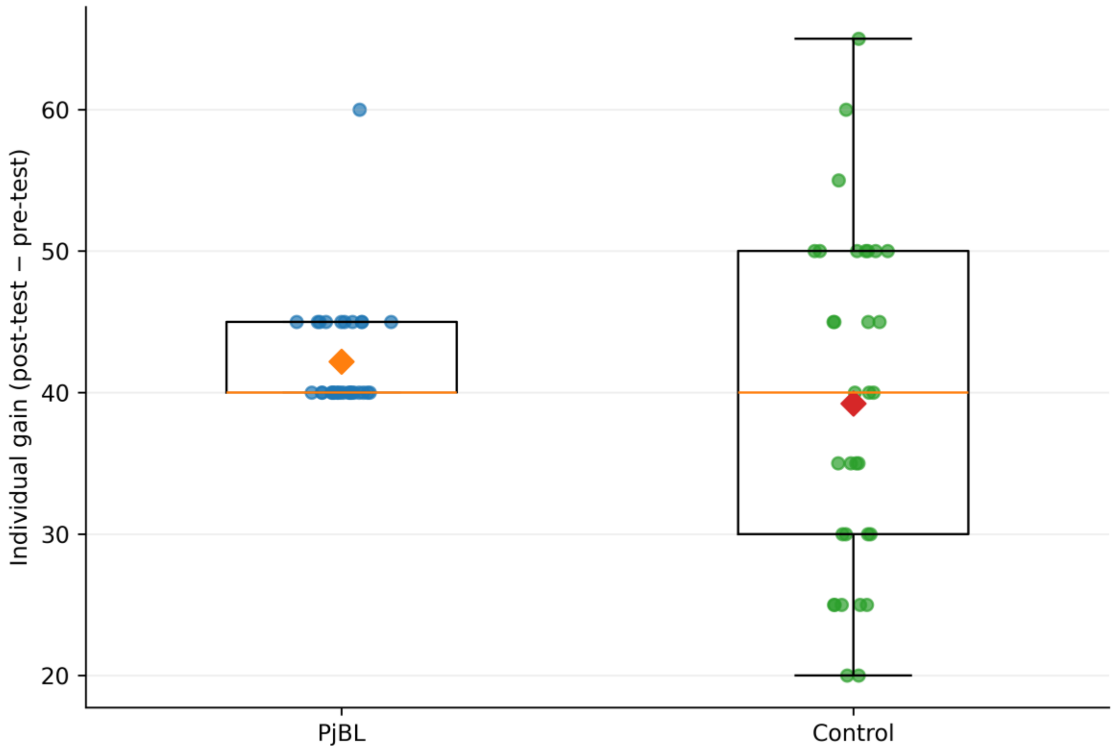

Fig. 2. Distribution of individual competency gains by instructional group. Diamonds indicate group means; boxes summarize the median and interquartile range. PjBL gains are concentrated in a narrow interval, whereas control gains are widely dispersed.

3.1.4 Consistency and dispersion of competency gains

The most pronounced difference between conditions concerns the variability of individual improvement. PjBL gains had a standard deviation of only 4.00 points and an interquartile range from 40 to 45 points. In contrast, control-group gains had a standard deviation of 11.99 points and an interquartile range from 30 to 50 points. The gain range was 40–60 in the PjBL group but 20–65 in the control group. Put differently, the control-group standard deviation was almost three times the PjBL standard deviation, and the control-group variance was approximately 8.97 times as large.

Robust tests indicate that this difference in dispersion is unlikely to be a chance feature of the observed sample. The median-centered Brown-Forsythe/Levene statistic was 37.70 with $p < 0.001$. The Fligner-Killeen test, which is less dependent on normality, also rejected equal dispersion ($\chi^2 = 24.25$, $p < 0.001$). These converging tests support H2: the distribution of competency gains under PjBL was substantially more concentrated than the distribution in the control class.

Figure 2 makes this difference visible at the student level. Most PjBL gains are tightly clustered around 40–45 points, with only a small number of larger gains. Control gains occupy a much wider vertical range.

Importantly, this is not simply the result of a difference in mean; the two medians are both 40 points. The groups therefore have similar centers but markedly different spreads. Figure 3 presents the empirical cumulative distributions and further shows how rapidly the PjBL gain distribution accumulates around a narrow interval, whereas the control distribution rises progressively across a much broader range.

The individual values sharpen the interpretation. All 32 students in the PjBL group gained at least 40 points. In the control group, 17 of 32 students gained at least 40 points, while 15 students gained less than 40 points. The control group also contained several students with gains larger than most PjBL gains, including improvements of 55–65 points. Thus, PjBL did not simply shift every student to the highest possible gain. Instead, the data indicate compression of learning outcomes around a consistently large improvement. The control condition produced both weaker and stronger individual responses, yielding substantially greater heterogeneity.

This pattern is educationally different from a conventional mean-effect result. If the objective is to maximize the average score only, the estimated 2.97-point gain advantage is the relevant effect and is uncertain. If the objective is to ensure that foundational competence develops reliably across the class, the narrow PjBL gain distribution becomes substantively important. For technical skills in which large learning deficits can compromise subsequent workshop performance, the dispersion of gain may be an outcome with direct instructional relevance.

Table 2. *Inferential comparisons of baseline, final performance, learning gain, and gain dispersion.*

Contrast	Estimate (95% CI)	Test	p	Effect / interpretation
Pre-test: PjBL - Control	-0.16 (-3.71 to 3.40)	Welch t(61.95) = -0.09	0.930	Hedges' g = -0.02
Post-test: PjBL - Control	2.81 (-1.36 to 6.98)	Welch t(61.86) = 1.35	0.183	Hedges' g = 0.33
Gain: PjBL - Control	2.97 (-1.56 to 7.49)	Welch t(37.83) = 1.33	0.192	Hedges' g = 0.33
PjBL pre-post gain	42.19 (40.74 to 43.63)	paired t(31) = 59.61	<0.001	Cohen's dz = 10.54
Control pre-post gain	39.22 (34.90 to 43.54)	paired t(31) = 18.51	<0.001	Cohen's dz = 3.27
Gain dispersion	Variance ratio = 8.97	Brown-Forsythe = 37.70	<0.001	Control variance > PjBL
Gain dispersion, robust	-	Fligner-Killeen = 24.25	<0.001	Confirms heterogeneity

Note. Positive between-group estimates favor PjBL. The gain variance ratio is control variance divided by PjBL variance. Within-group effect sizes describe change and should not be interpreted as treatment effects.

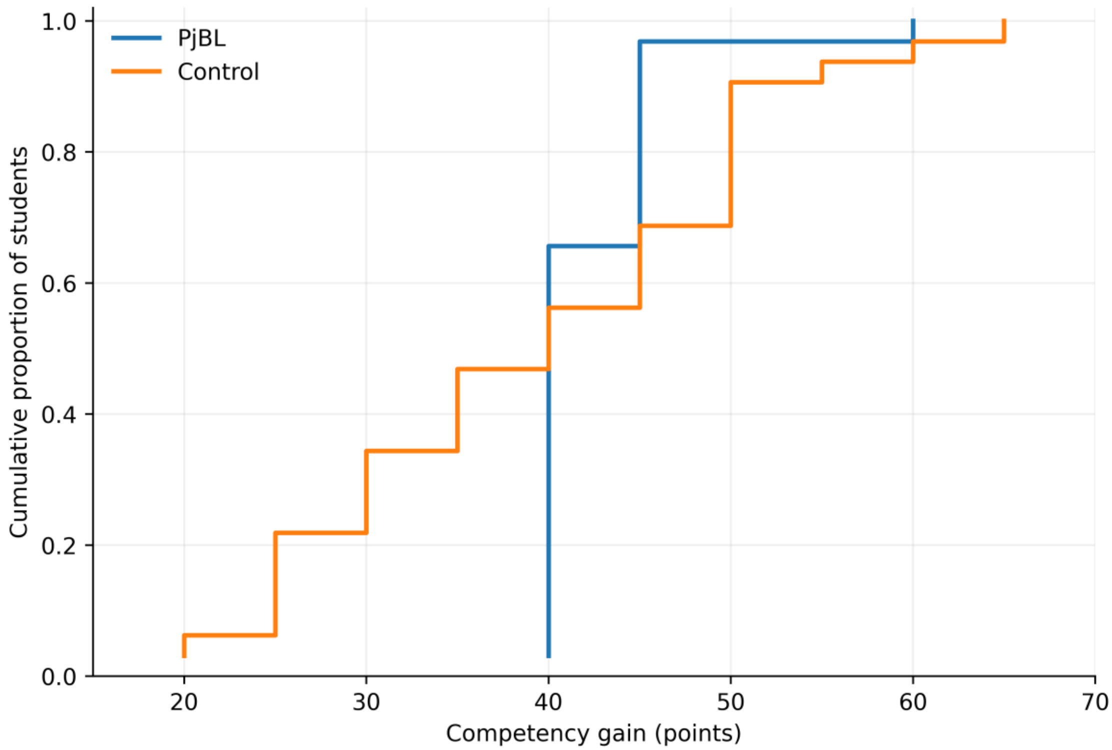

Fig. 3. Empirical cumulative distribution of individual competency gains. The steeper PjBL curve reflects the concentration of improvement around 40-45 points, while the control distribution spans a broader range.

3.1.5 Baseline-post-test relationships

The relationship between initial and final scores differed noticeably across the two classes. In the PjBL group, pre-test and post-test scores were strongly positively correlated (Pearson $r = 0.884$, $p < 0.001$; Spearman $\rho = 0.884$, $p < 0.001$). Because individual PjBL gains were comparatively uniform, students who entered with higher scores tended to retain their relative position while the entire distribution shifted upward. Pearson correlation between pre-test score and gain was weak ($r = 0.086$, $p = 0.642$), although the Spearman association was modest and positive ($\rho = 0.352$, $p = 0.048$), reflecting the discrete structure of the score values.

In the control group, pre-test and post-test scores were not significantly correlated (Pearson $r = -0.248$, $p = 0.171$; Spearman $\rho = -0.275$, $p = 0.128$). Instead, baseline score was strongly negatively associated with gain (Pearson $r = -0.753$, $p < 0.001$; Spearman $\rho = -0.765$, $p < 0.001$). Lower-scoring control students often showed larger gains, whereas some higher-scoring students improved less. Figure 4 illustrates these contrasting pre-post relationships. This pattern should not automatically be interpreted as a causal mechanism; it may reflect the instructional response, ceiling constraints, regression toward the mean, properties of the assessment, or class-specific processes. Nevertheless, it helps explain why the control group produced much greater gain variability.

The differing slopes are also a reason to avoid relying on a conventional common-slope ANCOVA as the sole adjusted analysis. An exploratory model including a pretest-by-group interaction produced a strong interaction, indicating that the relationship between baseline and post-test performance is not adequately represented by a single shared regression slope. The more transparent interpretation for the present dataset is therefore based on the observed pretest equivalence, direct gain comparison, and distributional analysis of gains.

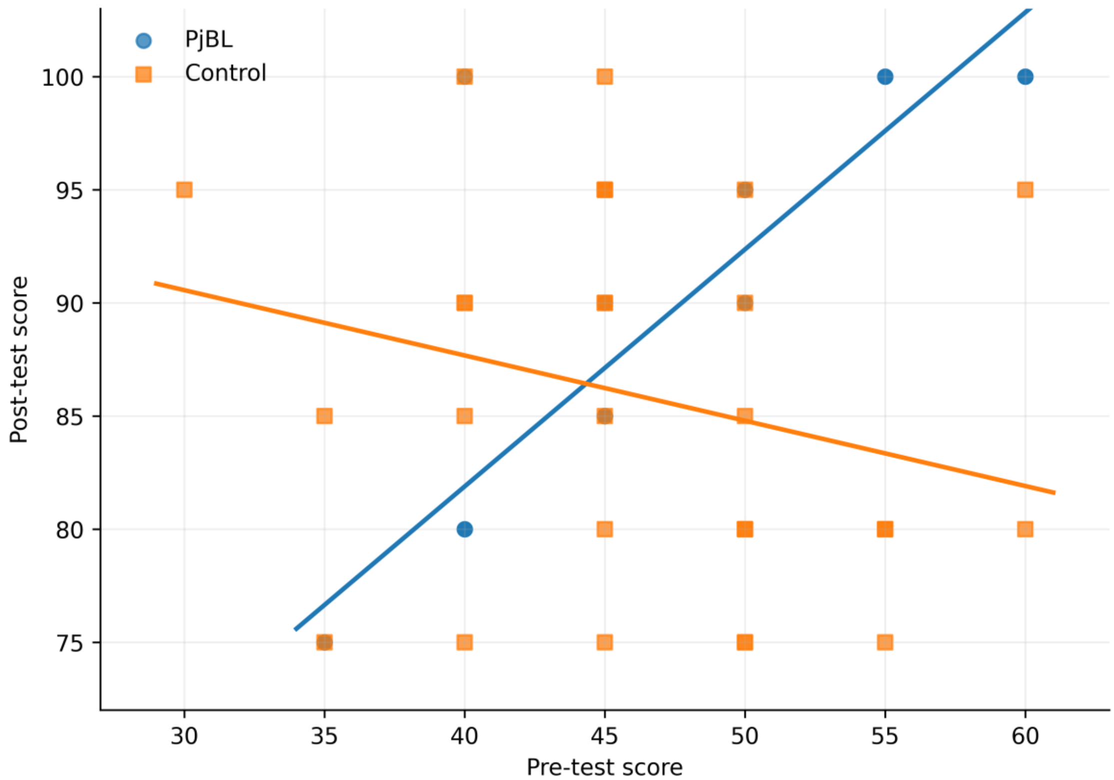

Fig. 4. Relationship between pre-test and post-test scores by group. The PjBL group shows a strong positive baseline-post-test association, consistent with a relatively uniform upward shift; the control group shows a weaker relationship and substantially more variable gains.

3.2 Discussion

3.2.1 Principal findings

This study examined PjBL in a narrowly defined but educationally consequential automotive competency: the use of a dial indicator. Three findings form the evidential core. First, the two classes entered the instructional period with essentially identical mean pre-test performance. Second, both classes demonstrated very large improvements, and the PjBL class ended with modest numerical advantages in post-test score and gain. Third, and most distinctly, the PjBL class displayed a much narrower distribution of individual gains. The average between-group advantage did not reach conventional statistical significance, whereas the difference in gain dispersion was large and supported by two robust variance tests.

The direction of the mean difference is compatible with a substantial body of vocational PjBL research. Positive group contrasts have been reported for technical drawing using real objects, STEAM-based welding, video-supported multilevel turning, blended PjBL, and technology-enhanced vocational learning (Giatman & Mukhaiyar, 2025; Handoyono & Johan, 2020; Hidayat et al., 2026; Huda et al., 2026; Rahim et al., 2024). Studies of integrated STEM-PjBL and automotive troubleshooting likewise report improvements in technical, cognitive, or diagnostic outcomes (Fadillah, 2025; Hasan et al., 2026; Rahim et al., 2025). However, the present data do not reproduce the clear mean superiority reported in several of those studies. The appropriate comparative statement is therefore not that PjBL "significantly outperformed" the control condition, but that it showed a small-to-moderate directional advantage in average gain while producing a much more distinctive change in the distribution of gains. This distinction prevents statistically strong within-group improvement from being mistaken for a statistically established treatment effect.

3.2.2 Mean effectiveness versus reliability of competency development

The distinction between mean effectiveness and reliability of learning is central to interpreting vocational outcomes. A mean score answers the question, "How well did the class perform on average?" Variability answers a different question: "How dependably did the instructional condition produce similar progress across individual learners?" This second question is especially relevant where students begin with heterogeneous readiness and where practical competence must be demonstrated by each learner rather than by the class collectively. Recent vocational research documents heterogeneity in learner preferences and perceived usefulness of teaching resources (Canut-Montalva et al., 2025), while practical-skills research highlights uneven readiness and the need for authentic, repeated, feedback-rich practice (Bascuguin & Generoso, 2026). A distributional perspective therefore complements, rather than replaces, the conventional focus on average achievement.

The present data illustrate why the distinction matters. The mean-gain difference was approximately three points, with a 95% confidence interval that crossed zero. Yet the control-group gain standard deviation was almost 12 points compared with only four points under PjBL. Control gains extended from 20 to 65 points, whereas PjBL gains were confined to 40–60 points and every PjBL student improved by at least 40 points. Because the medians were identical at 40, the principal difference cannot be described as a simple upward shift in central tendency. It is a difference in spread: the PjBL class experienced a comparatively compressed distribution around a large improvement. This reduced variability also has direct occupational relevance: automotive precision measurement depends on correct zero setting and repeatable readings, because inconsistent procedures can translate small measurement errors into different diagnostic judgments. From that perspective, the compressed PjBL gain distribution may indicate more uniform procedural control across learners—a desirable property when technical competence must be reproduced consistently rather than demonstrated only as a high class average.

This pattern has an instructive parallel in Asnur et al. (2025), who reported that a vlog-integrated PjBL variant in vocational culinary education produced a consistent distribution of scores across different ability levels and reduced performance gaps. The contexts and interventions are not equivalent, so the studies should not be treated as direct replications. Nevertheless, both point to an underexamined possibility: instructional design may affect not only how much a class improves on average but also how evenly benefits are distributed. In competency-based training, low variability is meaningful only when paired with adequate performance; uniformly poor scores would not constitute success. Here, the low dispersion occurred alongside a mean post-test score of 88.59 and a mean gain exceeding 42 points, making the combination of strong improvement and concentrated gains the educationally relevant signal.

The distributional finding also extends the way PjBL effectiveness is typically framed in the reviewed literature. Reviews and bibliometric studies emphasize achievement, employability, problem solving, critical thinking, collaboration, and other 21st-century competencies (Ahmad et al., 2023; Ibrahim, 2025; Megayanti et al., 2020), but variability of individual gain rarely appears as a focal endpoint. At the same time, the literature acknowledges substantial variation in PjBL design and learner response (Kaushik & Joshi, 2020; Sidik et al., 2026). The contribution of the present study is therefore analytical as well as substantive: for a foundational technical skill, dispersion of change may be a useful indicator of competency assurance, particularly when average differences are modest.

3.2.3 Plausible pedagogical interpretation

A plausible explanation for the observed consistency is that project-oriented learning can organize practice around a common sequence of purposeful actions. Design-Build-Test projects in vocational education have been reported to strengthen the connection between theoretical knowledge and practical application (Ali et al., 2025), while PjBL in TVET has been associated with hands-on application, learner autonomy, and responsibility for learning (Green & du Plessis, 2023). In vocational computing, project work has also been used to structure teamwork, project management, abstraction, implementation, and analysis within a shared task sequence (Habibi et al., 2025). Applied to dial-indicator instruction, a project that requires a complete measurement workflow may reduce fragmentation by ensuring that learners repeatedly encounter setup, reference establishment, reading, interpretation, checking, and correction as connected parts of one technical performance.

The occupational meaning of the task may be equally important. Project designs that embed authentic or career-focused contexts can make the relationship between learning activity and vocational performance more explicit. Hamdani and Suherman (2021) argue for project structures that approximate industrial experience, while Zhang and Yeoh (2026) found that career-focused PjBL enhanced motivation and that motivation mediated gains in learning initiative and vocational skills. Pla-Campas et al. (2025) likewise linked project work in natural contexts with stronger perceptions of professional competence. A dial indicator is therefore pedagogically more than an instrument to be read: within an authentic task, its reading becomes evidence required to judge component condition or measurement quality. That functional purpose may encourage students to attend more closely to setup stability, repeatability, and interpretation.

A second plausible mechanism is the density and structure of feedback. Project work can create repeated cycles of attempt, observation, comparison, revision, and verification. Evidence from vocational science suggests that contextual project learning benefits from explicit and sustained scaffolding when higher-order performance is expected (Anwar et al., 2026), and project-based learning tools have been used to support planning, monitoring, and evaluation of learning processes (Ramdhayani & Purwoko, 2023). In technical settings where authentic practice is emphasized, learners themselves identify collaboration, self-directed exploration, and challenge-with-reward as salient features of practical learning (Bascuguin & Generoso, 2026). If the PjBL class in the present study experienced more systematic corrective cycles, procedural errors could have been resolved before they accumulated into large between-student differences.

These mechanisms remain hypotheses rather than measured explanations. The dataset contains outcome scores but no measures of time-on-task, feedback frequency, peer interaction, project quality, number of measurement trials, or fidelity to PjBL syntax. The literature itself warns against treating PjBL as a uniform package: implementation depends on project design, scaffolding, assessment, teacher capacity, resources, and organizational support (González et al., 2026; Sidik et al., 2026). Consequently, the observed compression of gains should be attributed only to the instructional condition as implemented in these classes, not to a specific unmeasured mechanism.

3.2.4 Interpretation of the non-significant mean difference

The absence of a statistically significant between-group mean difference should not be interpreted as evidence of equivalence. The 95% confidence interval for the gain difference, approximately -1.56 to 7.49 points, contains both a small control advantage and a potentially meaningful PjBL advantage. The sample therefore leaves genuine uncertainty about the average treatment contrast. This is important because several vocational quasi-experiments in the reviewed literature report statistically significant advantages for project-oriented interventions, including technical drawing, blended PjBL, STEM-PjBL, and PjBL-MOOC designs (Handoyono & Johan, 2020; Köpeczi-Bócz, 2024; Rahim et al., 2024; Subandi et al., 2020). The present result shows that positive PjBL effects should not be presumed across tasks and contexts, particularly when samples are small and implementation differs.

Hedges' $g = 0.33$ for the gain difference provides a complementary estimate. The point estimate is consistent with a small-to-moderate advantage, but its uncertainty is substantial with 32 students per group. Other vocational studies have used ANCOVA or repeated-measures designs to improve precision or separate baseline effects (Hao et al., 2024; Wulansari et al., 2022). In the present dataset, however, the baseline-post-test relationship differed markedly between groups, making a simple common-slope ANCOVA less defensible as the sole adjusted analysis. A future multisite study should prespecify the estimand, account for classroom clustering, and choose a sample size based on the smallest educationally important difference rather than on whether a pilot p-value crosses 0.05.

It is equally important not to overstate the enormous within-group standardized changes. Cohen's dz values above 3 in both groups indicate that pre-post change was large relative to the variability of paired differences, but they do not isolate the causal contribution of PjBL. Both groups received instruction and both improved substantially. Familiarity with the assessment, ordinary teaching, practice effects, maturation, or common curriculum exposure could contribute to change. The treatment-relevant evidence is the contrast in changes between groups and the contrast in their distributions, not the significance of two separate paired tests.

3.2.5 Implications for automotive vocational instruction

For teachers of Pekerjaan Dasar Otomotif, the findings support designing projects around observable competency evidence rather than around project completion alone. Integrated vocational projects have been assessed through performance rubrics covering design, manufacture, operation, assembly, improvement, and performance (Arbiyanti & Artanto, 2020), while PjBL development for vocational welding emphasizes explicit performance objectives such as machine setup, operation, and visual inspection (Muhtar, Suryanti, Bachri, Kurniawati, et al., 2025). A dial-indicator project can adopt the same principle: every learner should demonstrate instrument mounting, contact alignment, reference setting, reading, repeat measurement, and interpretation, even when the wider project is collaborative.

The narrow gain distribution under PjBL also suggests that formative monitoring should be individual rather than inferred from group progress. Students who obtain unstable readings can be asked to diagnose stand rigidity, contact orientation, preload, or repeatability before moving to the next project stage. Project-based instructional media and mobile-supported PjBL have been reported to facilitate competence development by structuring access to project instructions and learning resources (Syahril et al., 2020; Setiawan et al., 2020). Such supports could be used not as substitutes for workshop practice, but as checkpoints that make the technical logic of correction visible and reproducible.

Assessment alignment is equally important. In outcome-based vocational education, PjBL and assessment strategies have both been positively associated with graduate-competence attainment (Li & Rohayati, 2024), and conceptual work on PjBL in technical colleges emphasizes planning, application, commitment, facilitation, and assessment as interdependent elements of implementation (Dogara et al., 2020). For precision measurement, an authentic scoring rubric should therefore reward not only the final numerical reading but the quality of the procedure used to obtain it. This would help determine whether a compressed gain distribution reflects genuine convergence in technical competence rather than compression caused by a coarse total-score instrument.

At the institutional level, the results argue for reporting dispersion and attainment alongside averages when evaluating practical instruction. Mean scores can obscure a lower tail of learners who have not progressed sufficiently. Standard deviation, interquartile range, empirical cumulative distributions, and the proportion meeting an officially defined competency threshold provide complementary information. The broader PjBL literature supports this emphasis on context and alignment: vocational PjBL is increasingly embedded in curricula to develop both technical and transferable competencies, but the quality of implementation depends on how learning outcomes, projects, and assessment are coordinated (Muhtar, Suryanti, Bachri, Mila, et al., 2025; Yusuf et al., 2023).

3.2.6 Limitations

Several limitations constrain interpretation. First, the analysis is based on two intact classes, one experimental and one control. Without documented random assignment or multiple clusters per condition, the treatment label is confounded with class membership. Teacher behavior, classroom climate, peer composition, scheduling, attendance, or other class-level factors could therefore contribute to the observed pattern. Huang et al. (2026), using a non-equivalent control-group design in secondary vocational education, similarly cautioned that quasi-experimental findings without full random assignment should be interpreted as associative rather than definitive causal evidence. The same restraint is warranted here.

Second, the study records provides total scores but not the full assessment instrument or evidence of measurement quality. It is not possible to determine from the dataset alone whether the score primarily represents conceptual knowledge, procedural knowledge, psychomotor execution, or a composite. Reliability, inter-rater agreement, rubric structure, and content validity are also undocumented. This matters because vocational competence is multidimensional and because compressed gain scores can partly reflect assessment design. Future work should use performance-based authentic assessment aligned with explicit technical criteria, an approach also emphasized in vocational instructional-design research (Muhtar, Suryanti, Bachri, Kurniawati, et al., 2025).

Third, intervention fidelity is not quantified. The study records identify PjBL as the experimental model but does not report project duration, grouping, teacher facilitation, feedback cycles, equipment access, or the pedagogy used in the control class. This limitation is consequential because PjBL effectiveness is sensitive to teacher and student roles, equipment, learning environment, and scaffolding (Megayanti et al., 2020), while systematic evidence identifies time, readiness, collaboration, and resources as recurring implementation challenges (Sidik et al., 2026). Vocational case studies also show that leadership support and collaborative culture shape sustained PjBL implementation (González et al., 2026). A replication should therefore include an intervention protocol and fidelity checklist. Classroom-based STEM-PjBL research also reports time management, uneven student involvement, and the need to align projects closely with learning topics as practical challenges (Rahmawati et al., 2021).

Fourth, the outcome was measured immediately after instruction, with no delayed retention or transfer test. Precision-measurement competency has practical value only if learners can reproduce the procedure later and apply its principles to different components or diagnostic situations. Ibrahim’s (2025) bibliometric analysis identifies the scarcity of longitudinal evidence as an important gap in PjBL research, and Asnur et al. (2025) specifically recommend examining long-term skill retention in future vocational PjBL studies. The present results therefore concern immediate learning gain, not durable mastery.

Fifth, post-test scores are relatively high and the scale is bounded at 100, creating potential ceiling constraints. Multiple PjBL students achieved the maximum score. Ceiling effects can compress final-score variability and may influence gain patterns for students who begin at different baselines. The main consistency finding remains notable because the gain distribution itself is highly concentrated, but a more discriminating performance instrument would permit stronger inference about high-level mastery and reduce the risk that score compression is partly a measurement artifact.

3.2.7 Directions for further research

A stronger next study should replicate the comparison across several classes and schools and, where feasible, randomize classes or students to instructional conditions. Multilevel models could then separate learner-level effects from teacher- and class-level variation. Studies in vocational education already demonstrate the feasibility of larger quasi-experimental designs and repeated measurement across multiple groups (Huda et al., 2026), while systematic reviews emphasize that pedagogical effects are embedded within institutional and technological conditions (Polatuly et al., 2026). Sample-size planning should be based on a prespecified smallest effect of educational interest and should consider power for both mean and variance contrasts.

Future research should also decompose dial-indicator competency into technically meaningful components: instrument setup, reference establishment, contact alignment, reading accuracy, repeatability, interpretation, and procedural safety. Such decomposition would distinguish a genuine psychomotor/procedural effect from improvement in a composite score. Vocational PjBL research in different domains shows the value of assessing specific practical competencies and not only general achievement, including multilevel turning performance and automotive diagnostic accuracy (Hidayat et al., 2026; Hasan et al., 2026). Process measures such as number of trials, corrective feedback episodes, time to stable measurement, and error type could then test the mechanisms proposed here.

Finally, the consistency hypothesis deserves explicit theoretical development. PjBL may reduce between-student variability when a shared authentic workflow, repeated corrective cycles, and clearly aligned assessment constrain the number of ways in which learners can omit or misunderstand critical procedural steps. Yet project learning can also amplify differences if tasks are insufficiently scaffolded or if participation within teams is unequal. Evidence from vocational education shows both the importance of structured contextual learning and the influence of motivation, engagement, and project design on competency development (Astudillo & Illescas, 2025; Lamada et al., 2026; Zhang & Yeoh, 2026). Future studies should therefore ask not only whether PjBL raises the average, but for whom it works, through which processes, and whether it improves the reliability with which technical competence is acquired.

CONCLUSION

Project-Based Learning was associated with substantial improvement in dial-indicator competency among Grade X Light Vehicle Engineering students, but the data do not justify a simple claim of statistically significant superiority in average performance. The PjBL group improved by 42.19 points on average compared with 39.22 points in the control group, yielding a 2.97-point advantage that was positive but statistically uncertain. The more distinctive finding was the distribution of improvement: PjBL gains were highly concentrated, with a standard deviation of 4.00 points compared with 11.99 points in the control group, and robust tests strongly rejected equal gain variability. Every PjBL student improved by at least 40 points, whereas control gains ranged from 20 to 65 points.

The central contribution of this study is therefore a broader conception of instructional effectiveness in vocational learning. For a foundational precision-measurement skill, the educational objective is not only to raise the class mean but to ensure dependable progression across learners. The observed PjBL pattern is consistent with that objective: a large upward shift accompanied by substantially lower between-student variability. This finding should be interpreted as promising rather than definitive because the evidence comes from two intact classes and the study records does not document random allocation, intervention fidelity, or assessment reliability. Nevertheless, the analysis identifies a testable proposition for future research: project-based instruction may be particularly valuable in automotive vocational education when its effect is evaluated in terms of both the magnitude and the consistency of competency acquisition.

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