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Project-Based Learning Is Associated with Consistent Gains in Workplace Tools and Equipment Competence among Automotive Vocational Students: A Pre-Post Study

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ABSTRAK

Project-Based Learning (PjBL) banyak digunakan dalam pendidikan vokasi untuk menghubungkan pengetahuan dengan tugas yang bermakna, tetapi hasil pembelajaran sering dilaporkan hanya pada tingkat rata-rata kelas. Penelitian ini menganalisis besaran, konsistensi, dan distribusi perubahan kompetensi peralatan dan perlengkapan tempat kerja pada 31 siswa kelas X Teknik Otomotif setelah pembelajaran berbasis proyek. Data berupa skor pre-test dan post-test berpasangan dianalisis menggunakan statistik deskriptif, analisis gain individual, uji Shapiro-Wilk, uji Wilcoxon signed-rank sebagai analisis utama, paired-samples t test sebagai analisis sensitivitas, ukuran efek, dan korelasi. Rata-rata skor meningkat dari 48,39 (SD = 9,43) menjadi 72,77 (SD = 10,19), dengan peningkatan rata-rata 24,39 poin (95% CI 23,36-25,41). Seluruh 31 siswa mengalami peningkatan, dengan gain individual 20-28 poin. Uji Wilcoxon menunjukkan pergeseran pre-post yang signifikan ($W+ = 496$, $p < 0,001$), dan paired t test memberikan kesimpulan yang sama, $t(30) = 48,48$, $p < 0,001$. Skor awal tidak berhubungan dengan besarnya gain ($r = 0,135$, $p = 0,467$). Temuan menunjukkan peningkatan kompetensi berbasis tes yang besar dan sangat konsisten, namun desain satu kelompok tidak mendukung klaim kausal atau keunggulan PjBL dibandingkan metode lain.
Kata Kunci: Project-Based Learning, pendidikan vokasi, teknik otomotif, peralatan kerja, kompetensi

ABSTRACT

Project-Based Learning (PjBL) is widely used in vocational education to connect disciplinary knowledge with meaningful tasks, yet learning outcomes are often reported only as class averages. This study examined the magnitude, consistency, and distribution of change in workplace tools and equipment competence among 31 Grade X automotive vocational students following a project-based learning sequence. Paired pre-test and post-test scores were analyzed using descriptive statistics, individual gain analysis, the Shapiro-Wilk test, the Wilcoxon signed-rank test as the primary inferential procedure, a paired-samples t test as sensitivity analysis, standardized effect indices, and correlations. Mean scores increased from 48.39 (SD = 9.43) to 72.77 (SD = 10.19), yielding a mean gain of 24.39 points (95% CI 23.36-25.41). All 31 students improved, with individual gains ranging

from 20 to 28 points. The Wilcoxon test confirmed a marked pre-post shift (W+ = 496, p < .001), and the paired t test produced the same conclusion, t(30) = 48.48, p < .001. Baseline score was not associated with gain magnitude (r = .135, p = .467). The findings indicate a large and unusually consistent increase in test-based competence, although the one-group design does not establish causality or superiority over alternative instruction.
Keywords: *Project-based learning, vocational education, automotive engineering, workplace tools, competence development*

INTRODUCTION

Vocational education is expected to do more than transmit technical information. Its distinctive task is to help learners convert knowledge into competent action in situations that resemble the conditions of work. Recent vocational studies repeatedly frame this theory-practice connection as a central instructional problem. Design-build-test projects in technical education have been used specifically to connect conceptual learning with practical application, while project-oriented hospitality learning has been associated with deeper understanding, autonomy, and employability-related skills (Ali et al., 2025; Green & du Plessis, 2023). In vocational high schools, PjBL has likewise been positioned as an adaptive response to industry expectations for technical and transferable skills (Dzulkurnain et al., 2024). These observations are particularly relevant to automotive education, where knowledge becomes consequential when learners can recognize the purpose of a tool, select it appropriately, and relate its use to a technical task.

Project-Based Learning has become a prominent part of this broader shift toward active and practice-oriented vocational pedagogy. A bibliometric analysis of Scopus-indexed work between 2010 and 2022 identified PjBL as a well-developed and increasingly important theme in vocational education, with Indonesia among the most active national contributors (Ahmad et al., 2023). A later bibliometric analysis covering 1993-2023 similarly described growing interest in PBL across vocational and STEM fields, while also identifying unresolved gaps in longitudinal evidence and comparative effectiveness against traditional pedagogies (Ibrahim, 2025). The field is therefore no longer at a stage where the mere use of PjBL constitutes novelty. A stronger contribution requires specificity about what competence is being developed, how improvement is measured, whether gains are distributed across learners, and what claims the study design can legitimately support.

Empirical studies across vocational domains provide a substantial rationale for asking these more precise questions. In secondary TVET, Isa and Azid (2021) reported better learning performance for a PBL treatment group than for a comparison group. In welding education, a PjBL-STEAM intervention produced higher gains across cognitive, affective, and psychomotor domains than traditional teaching (Rahim et al., 2024). Project-based and flipped approaches have also been associated with improvements in critical thinking, creativity, motivation, and achievement in higher vocational settings (Hao et al., 2024; Köpeczi-Bócz, 2024). More recently, technology-supported variants have reported improvements in critical thinking, engagement, learning achievement, or problem solving, although these studies evaluate different learner populations and different outcome constructs (Hwang et al., 2026; Sardi et al., 2025; Saputro & Budiarto, 2026). Taken together, this literature supports the plausibility of PjBL as a vocational pedagogy, but it does not make the outcome of any specific automotive intervention self-evident.

The automotive context is especially important because foundational competence precedes complex diagnosis and repair. Two recent studies show the emerging relevance of project-oriented approaches in automotive-related vocational learning. Anwar et al. (2026) developed a contextual science project module for Grade X Automotive Light Vehicle Technology students and reported moderate overall gains in critical thinking, with stronger improvement on some indicators than on inference. Hasan et al. (2026) integrated augmented-reality simulation into a project-based troubleshooting model for an automotive chassis course and reported higher engagement, conceptual understanding, diagnostic accuracy, and problem-solving performance than a comparison condition. These studies demonstrate that project-oriented designs can be productively applied in automotive-related curricula, but they address science/critical thinking and chassis troubleshooting rather than the more elementary competence of workplace tools and equipment that underpins later workshop activity.

That distinction matters. Workplace tools and equipment are enabling resources in automotive practice: later operations depend on whether learners can connect a job requirement with the appropriate instrument, equipment, safety logic, and sequence of work. Project-oriented learning can potentially make those relationships visible by organizing content around a purposeful task instead of a list of tool names or functions. Related vocational models emphasize this same movement toward contextualized competence. Self-design PjBL has been proposed to give learners experience that resembles industrial work (Hamdani & Suherman, 2021), product-oriented project models seek to connect practical activity with authentic outputs (Haq et al., 2024), and a vocational welding curriculum developed through the Dick and Carey framework explicitly links project goals, workshop resources, competency standards, and performance-based assessment (Muhtar et al., 2025). The common principle is not simply "learning by doing," but aligning what students do with what they are expected to understand and eventually perform.

A second issue is learner heterogeneity. Vocational classrooms are not homogeneous in prior knowledge, motivation, access to equipment, or learning preferences. Students in intermediate vocational training show marked variation in the perceived usefulness of instructional resources even while generally preferring practical activities (Canut-Montalva et al., 2025). In computer-oriented VET, active methodologies have been applied to groups explicitly described as heterogeneous in background, skills, and motivation (Díaz-Lauzurica & Moreno-Salinas, 2025). Project-based differentiation research further suggests that a shared project structure can accommodate level-appropriate tasks without fragmenting common outcomes (Bakshi, 2026). Such findings make the distribution of improvement an important outcome in its own right. A mean gain can appear impressive while hiding unchanged or declining students; conversely, a similar mean produced by near-universal improvement has a different educational meaning.

Evidence from vocational PjBL also suggests that project design can interact with diversity rather than erase it. In culinary education, a vlog-integrated PjBL model produced high learning gains and a relatively consistent distribution of outcomes across students with different ability levels (Asnur et al., 2025). In technical education, experiential-learning research has found only weak relationships between preferred learning style and performance, suggesting that learner progress may not be reducible to fixed style categories (Goncalves, 2024). At the same time, practice-centered studies highlight uneven learner readiness and the need for repeated, feedback-rich instruction (Bascuguin & Generoso, 2026). These

strands of evidence motivate analysis at the individual level: not only whether a class improves, but whether lower- and higher-starting students participate in that improvement.

The Indonesian vocational context adds further relevance. Recent studies describe PjBL as a prominent component of vocational curricular reform and student experience. Indonesian vocational college students have reported positive attitudes toward mandatory PjBL in English courses, with perceived language-skill benefits linked to career aspirations (Mutiaraningrum et al., 2024b), while other work has connected classroom projects with entrepreneurial knowledge and intentions (Mutiaraningrum et al., 2024a). PBL has also been used to operationalize character-oriented project learning in Indonesian vocational settings, with planning, execution, product development, and evaluation treated as explicit stages (Kholifah et al., 2025). A systematic review of Indonesian vocational education for Industry 5.0 further identifies PjBL, Teaching Factory, and technology-enhanced learning among the dominant pedagogical strategies for developing technical and transferable competencies (Sukis et al., 2026). The question is therefore not whether PjBL is relevant to Indonesian vocational education, but how convincingly its outcomes are demonstrated in particular competence domains.

The present study focuses on a narrow but foundational domain: Peralatan dan Perlengkapan Tempat Kerja (Workplace Tools and Equipment) in Pekerjaan Dasar Teknik Otomotif (PDTO; Basic Automotive Engineering Work). The available dataset contains paired pre-test and post-test scores for 31 Grade X automotive students taught using PjBL. This design permits analysis of four features that are often compressed into a single significance test: the magnitude of the class-level shift, the direction and size of each student's change, the stability of improvement across different starting scores, and the statistical robustness of the paired difference. The study therefore treats consistency of learning gain as part of the substantive contribution rather than as a descriptive afterthought.

The research gap is formulated conservatively. Existing literature shows that PjBL can support vocational achievement, practical learning, critical thinking, engagement, autonomy, and work-related skills across diverse settings (Habibi et al., 2025; Li & Rohayati, 2024; Pla-Campas et al., 2025; Wulansari et al., 2022). However, the supplied literature does not provide direct evidence on the individual distribution of pre-post gains in introductory automotive workplace-tools competence. Nor does it establish that a positive class mean necessarily represents broad benefit across a heterogeneous cohort. Addressing this gap is useful because foundational tool competence can constrain participation in later workshop tasks, and because a cohort-wide shift has different pedagogical implications from an average improvement concentrated among a subset of students.

Accordingly, this study asked three questions. First, how large was the change in workplace tools and equipment competence after the PjBL instructional period? Second, was that change broadly distributed across students or driven by a small number of high responders? Third, was gain magnitude associated with baseline competence? The corresponding hypothesis was that post-test scores would be substantially higher than pre-test scores and that positive change would be observed across the cohort. Because the study contains no contemporaneous comparison group, the inferential target is within-student change associated with the instructional period, not proof that PjBL is causally superior to another teaching method. This distinction aligns with the wider literature's call for stronger comparative and longitudinal evidence rather than overextension of single-group findings (Ibrahim, 2025). The study’s contribution therefore lies in documenting the distribution and consistency of competence gains

in a foundational automotive domain, rather than in claiming novelty for PjBL as a pedagogical approach.

METHOD

2.1 Study design and analytical scope

This study used a one-group pre-test-post-test design to evaluate change in student competence scores before and after implementation of Project-Based Learning. The individual student was the analytical unit because each learner contributed a matched pair of observations. The design is appropriate for quantifying within-cohort change and examining how improvement is distributed across participants. It is not equivalent to a randomized or quasi-experimental comparison and therefore cannot isolate the causal effect of PjBL from other time-varying influences. The manuscript consequently reports a classroom intervention study and uses cautious language such as "following" or "associated with" PjBL rather than claiming superiority over conventional instruction.

2.2 Participants and educational context

The dataset comprised 31 students identified as members of a Grade X automotive class ("X Oto"). The recorded subject was Pekerjaan Dasar Teknik Otomotif (PDTO; Basic Automotive Engineering Work), and the instructional material was Peralatan dan Perlengkapan Tempat Kerja (Workplace Tools and Equipment). Project-Based Learning was recorded as the learning model. Every participant had both a pre-test and a post-test score, yielding 31 complete paired observations. The supplied records did not include age, sex, prior workshop experience, school location, socioeconomic characteristics, previous academic achievement, or other demographic variables. No such characteristics were inferred or imputed. This restriction prevents subgroup analysis and should be considered when interpreting generalizability.

2.3 Project-Based Learning intervention

The source record identifies the intervention as Project-Based Learning but does not document its duration, project brief, project product, group configuration, teacher prompts, assessment checkpoints, workshop facilities, or implementation-fidelity procedures. These elements were therefore not reconstructed. The intervention is described only at the level supported by the data: Grade X automotive students studied workplace tools and equipment through a PjBL sequence and completed assessments before and after that sequence. This reporting choice is intentionally conservative. The vocational literature indicates that PjBL implementation varies substantially in design and can depend on project structure, collaboration, teacher support, resources, and institutional conditions (González et al., 2026; Sidik et al., 2026). The absence of these implementation details is therefore a limitation rather than a license to invent them.

2.4 Outcome measure

The primary outcome was the numerical competence score recorded for the pre-test and post-test. Scores ranged from 32 to 68 at baseline and from 56 to 92 after instruction. The assessment was scored on a 0-100 scale, and observed values occurred in 4-point increments. The supplied records did not identify the number of items or item format (e.g., multiple-choice or structured scenarios), nor did they include the instrument blueprint, scoring rubric, reliability coefficient, content-validity evidence, pass threshold, or a direct practical-performance protocol. Accordingly, the outcome is described as a test-based competence score rather than as a complete measure of occupational performance. This distinction is consistent with current vocational assessment discussions, which increasingly emphasize the

importance of determining not only what students know but also what they can do in authentic or performance-oriented contexts (Baker & Ragavanis, 2025). Because the source file for this study did not contain such performance evidence, no hands-on proficiency claims are made.

2.5 Data preparation and descriptive analysis

The dataset was inspected for completeness and paired consistency before analysis. No values were missing. For each student, an individual gain score was calculated as post-test minus pre-test. Descriptive analysis included the mean, standard deviation, median, first and third quartiles, minimum, maximum, frequency distribution of gain values, and the proportion of students with positive, zero, or negative change. Individual trajectories were plotted to determine whether the mean difference concealed heterogeneous responses. This person-level emphasis was prespecified because a classroom intervention that improves the mean while leaving a substantial subgroup unchanged has different educational implications from an intervention associated with improvement across the entire observed cohort.

2.6 Statistical analysis

The inferential strategy was determined from the paired differences. The Shapiro-Wilk test was applied to gain scores rather than to the pre-test and post-test distributions separately, because the normality assumption for a paired t test concerns the distribution of within-person differences. Gain scores departed from normality ($W = 0.805$, $p < .001$) and were concentrated at three discrete values: 20, 24, and 28 points. The Wilcoxon signed-rank test was therefore treated as the primary inferential test. A paired-samples t test was retained as a sensitivity analysis because it directly estimates the mean paired difference and its confidence interval; concordance between the two approaches would show that the substantive conclusion was not dependent on a single distributional assumption.

2.7 Effect magnitude and exploratory associations

Effect magnitude was characterized using complementary indicators. The primary effect description was the raw mean change in score points with a 95% confidence interval, because this remains directly interpretable in the original outcome scale. The proportion of students showing positive change was reported as a second measure of consistency. Cohen's dz was calculated as the mean paired difference divided by the standard deviation of the paired differences. Because gain scores were unusually homogeneous, dz was expected to be very large and was interpreted cautiously. For a more conservative descriptive standardization, the mean change was also divided by the average pre/post standard deviation (d_{av}), and a small-sample-corrected Hedges-type g_{av} was reported. Pearson correlation quantified the association between pre-test and post-test scores and, separately, the association between baseline score and gain magnitude. The latter was exploratory and was not interpreted as a moderator analysis.

2.8 Decision criteria and interpretation

All statistical tests used an alpha level of .05. Extremely small p values are reported as $p < .001$. Statistical significance was not treated as synonymous with educational importance. Interpretation emphasized convergence among the mean change, confidence interval, nonparametric result, sensitivity analysis, individual trajectories, and gain distribution. This approach is especially important in the present dataset because the narrow dispersion of gain scores can generate unusually large standardized effects. Raw-score change and the proportion of learners improving are therefore given interpretive priority over a single standardized index.

RESULTS AND DISCUSSION

3.1 Descriptive change in competence scores

All 31 paired observations were complete and retained for analysis. Pre-test scores ranged from 32 to 68, with a mean of 48.39 (SD = 9.43), a median of 48, and an interquartile range of 40-56. These values indicate substantial variation in initial test-based competence. Post-test scores ranged from 56 to 92, with a mean of 72.77 (SD = 10.19), a median of 72, and an interquartile range of 64-80. The mean post-test score was therefore 24.39 points higher than the mean pre-test score. Table 1 summarizes the distributions of pre-test, post-test, and gain scores.

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

Measure	n	Mean (SD)	Median	Q1-Q3	Minimum	Maximum
Pre-test	31	48.39 (9.43)	48	40-56	32	68
Post-test	31	72.77 (10.19)	72	64-80	56	92
Gain	31	24.39 (2.80)	24	24-28	20	28

Note. Gain = post-test minus pre-test; Q1 = first quartile; Q3 = third quartile.

3.2 Individual-level consistency of improvement

The defining descriptive result was the uniform direction of individual change. Every participant obtained a higher post-test score than pre-test score: 31 of 31 students improved, while no student was unchanged and no student declined. Individual gains ranged from 20 to 28 points. Six students gained 20 points, 16 gained 24 points, and nine gained 28 points. The mean gain was 24.39 points (SD = 2.80), and the median gain was 24 points. Fig. 1 shows the paired trajectories and demonstrates that the increase was not driven by a small number of extreme responders. Fig. 3 shows the narrow gain distribution.

3.3 Distributional shift

The pre-test and post-test distributions indicate an upward translation of the class rather than convergence toward a single score. The post-test median was 24 points higher than the pre-test median, and the entire post-test range was shifted upward. At the same time, post-test scores remained dispersed from 56 to 92. Fig. 2 therefore shows two features simultaneously: overall improvement and continued between-student heterogeneity. PjBL implementation was followed by a higher competence distribution, but relative differences among learners were not eliminated.

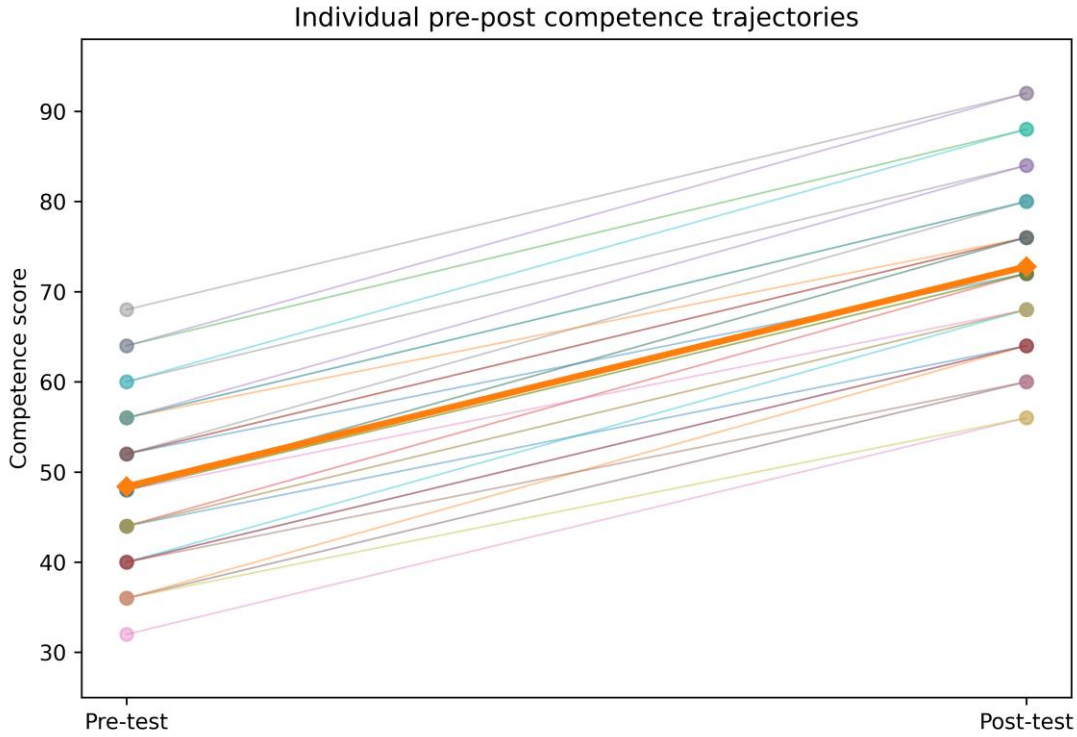

Fig. 1. Individual pre-test and post-test competence trajectories. Each thin trajectory represents one student; the emphasized trajectory represents the class mean.

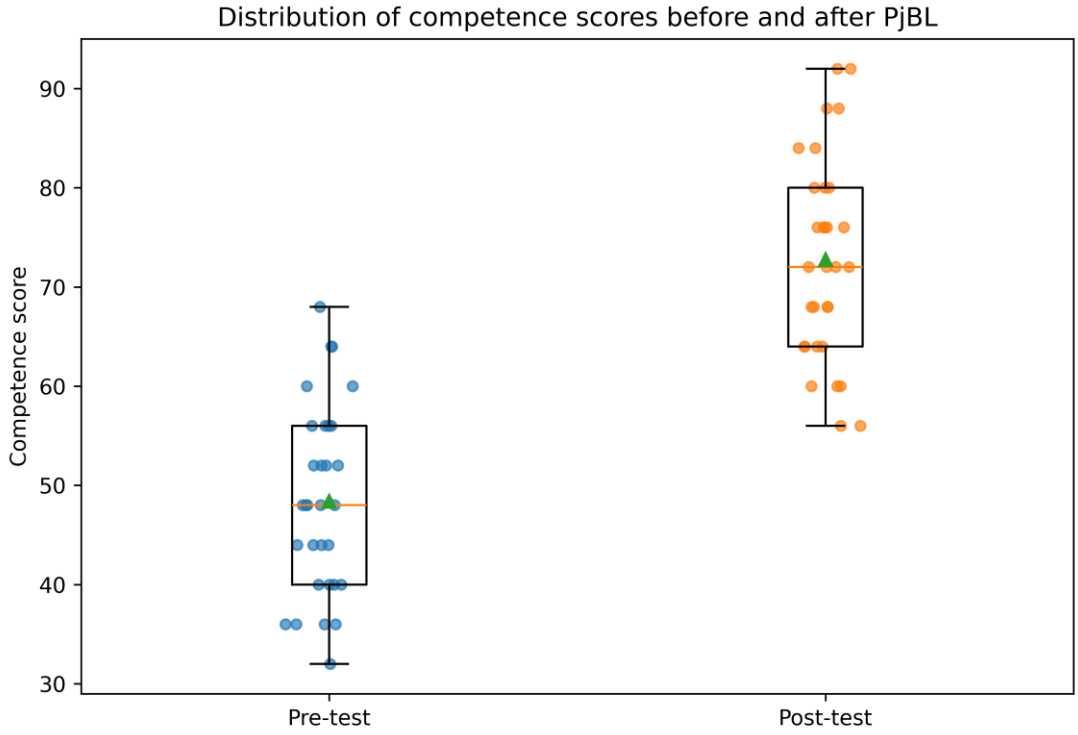

Fig. 2. Distribution of competence scores before and after Project-Based Learning. Points represent individual students; boxplots summarize the group distributions.

3.4 Inferential evidence and effect magnitude

Gain scores were non-normal (Shapiro-Wilk $W = 0.805$, $p < .001$), so the Wilcoxon signed-rank test was designated as the primary inferential analysis. All signed differences were positive, producing a positive-rank sum $W+ = 496$ and a highly significant pre-post shift (two-sided $p < .001$). The paired-samples t test yielded the same conclusion, $t(30) = 48.48$, $p < .001$. The estimated mean paired difference was 24.39 points, with a 95% confidence interval from 23.36 to 25.41. Thus, both distribution-free and parametric analyses support a substantial within-student increase.

Table 2. Inferential and consistency indicators for pre-post change.

Indicator	Estimate	Interpretation
Mean paired difference	24.39 points (95% CI 23.36-25.41)	Substantial positive shift
Students with positive gain	31/31 (100%)	No unchanged or declining scores
Wilcoxon signed-rank	$W+ = 496$; $p < .001$	Primary nonparametric evidence
Paired t test	$t(30) = 48.48$; $p < .001$	Sensitivity analysis agrees
Cohen's dz	8.71	Inflated by very low gain-score variability; interpret cautiously
Hedges-type g_av	2.42	Large standardized pre-post shift
Pre-test vs post-test	$r = .962$; $p < .001$	Relative ranking broadly preserved
Pre-test vs gain	$r = .135$; $p = .467$	No evidence gain depended on baseline score

Note. Wilcoxon was designated primary because the distribution of paired differences was non-normal. Standardized effects are supplementary to raw-score change.

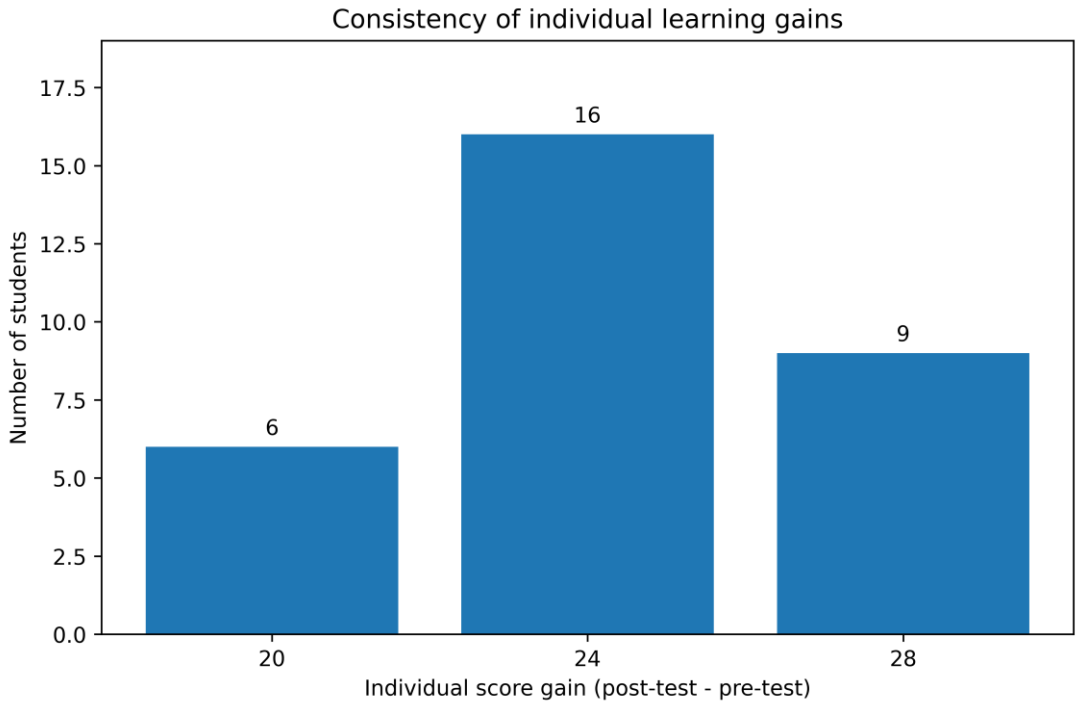

Fig. 3. Frequency distribution of individual gain scores. All observed gains were positive and were concentrated at 20, 24, or 28 points.

3.5 Standardized change and baseline associations

Cohen's dz was 8.71. This value is unusually large because the mean gain was large relative to the very small standard deviation of paired differences (2.80). It should therefore not be interpreted in isolation or compared mechanically with effect sizes from studies using more variable outcomes. Standardizing the same mean change against the average pre/post variability yielded $d_{av} = 2.48$ and a small-sample-corrected g_{av} of approximately 2.42, which still indicates a large shift. Pre-test and post-test scores were strongly correlated ($r = .962$, $p < .001$), showing that relative ranking was broadly preserved. By contrast, baseline score was not significantly associated with gain magnitude ($r = .135$, $p = .467$). Fig. 4 shows that all observations lie above the no-change line while retaining a strong linear relation between starting and ending scores.

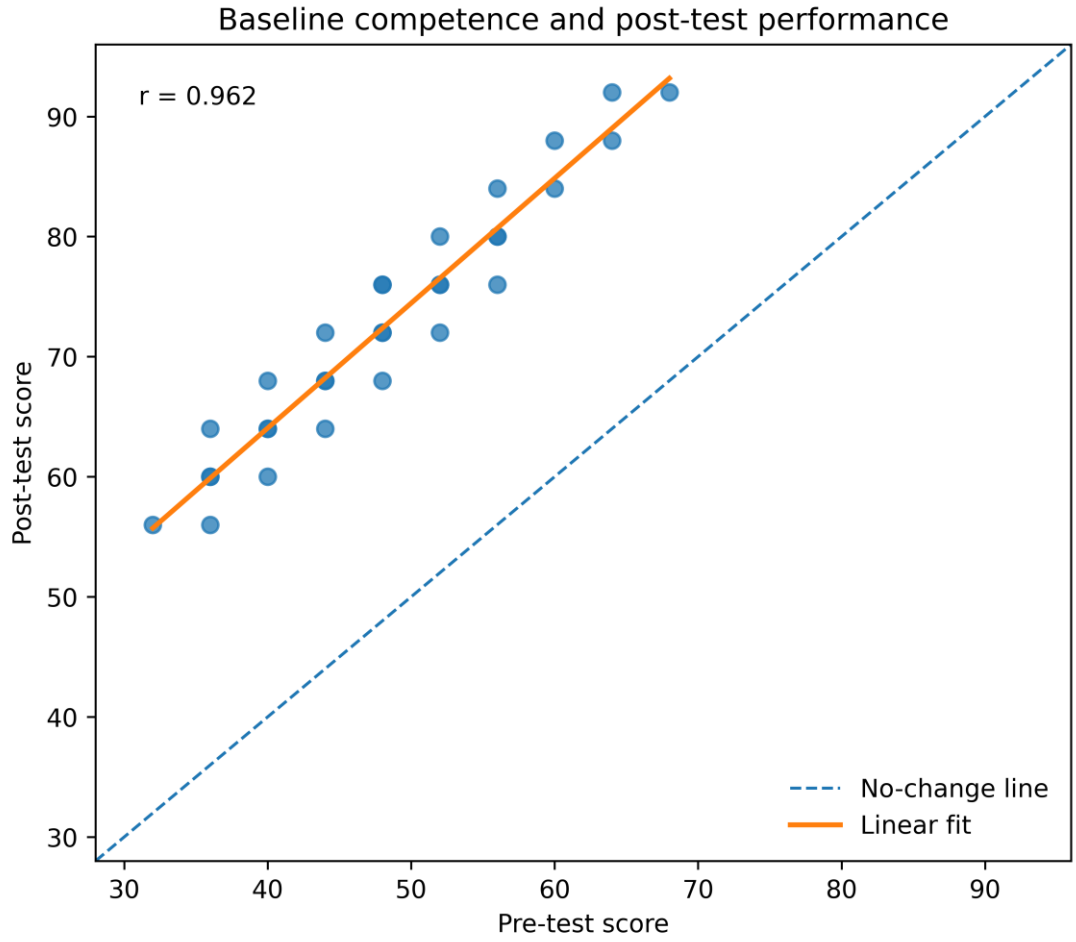

Fig. 4. Association between baseline and post-test competence. The dashed identity line denotes no change; every observation lies above this line.

4.1 Principal finding: a cohort-wide upward shift

The principal finding is more specific than a statistically significant difference between two means. The observed class increased by 24.39 points on average, but the educationally distinctive feature is that every student improved and that individual gains were confined to a narrow 20-28-point interval. This pattern indicates a cohort-wide upward shift rather than an average effect generated by a few high responders. The strong pre-post correlation further shows that improvement did not erase the original performance hierarchy: students who started higher generally remained higher. The combination of preserved ranking and universal positive change is best described as upward translation of the score distribution, not equalization of competence.

4.2 Positioning the result within vocational PjBL evidence

The direction of the result is consistent with a broad vocational literature showing that project-oriented approaches can improve learning outcomes, although direct numerical comparison is inappropriate because the studies differ in design, population, content, and measures. Isa and Azid (2021) found that secondary students in a PBL group outperformed a control group in project-design learning. Rahim et al. (2024) reported high N-gain values across cognitive, affective, and psychomotor domains in a vocational welding PjBL-STEAM intervention relative to traditional instruction. In higher vocational education, Hao et al. (2024) found significant effects of project-based and project-based

flipped approaches on critical thinking and creativity. These studies provide comparative evidence that the present pre-post increase is pedagogically plausible, but they do not remove the causal limitations of a one-group design.

4.3 Relevance to automotive and technical competence

The present study adds a different competence domain to this literature. Anwar et al. (2026) reported moderate overall gains in critical thinking from a contextualized science project module with Grade X Automotive Light Vehicle Technology students, while Hasan et al. (2026) reported improved conceptual understanding, diagnostic accuracy, engagement, and problem solving from an augmented-reality project-based troubleshooting model in an automotive chassis course. Those interventions target higher-order cognition and troubleshooting. The current outcome concerns workplace tools and equipment, a more foundational area that supports later diagnostic and repair activity. Its contribution is therefore not that PjBL has never been used in automotive education, but that a project-oriented sequence was associated with a highly consistent increase in a basic competence domain that precedes more complex workshop work.

4.4 Why project structure may matter for foundational tool learning

The literature offers several plausible explanations for why project organization can support vocational learning, although the present dataset cannot identify a mechanism directly. Design-build-test work in VTE has been reported to strengthen the connection between theoretical knowledge and practical application while increasing motivation and collaboration (Ali et al., 2025). Hospitality PjBL has been associated with learner autonomy, deeper subject understanding, and the opportunity to apply knowledge in meaningful activities (Green & du Plessis, 2023). Self-design PjBL has been explicitly developed to give vocational learners an experience closer to industrial work (Hamdani & Suherman, 2021), and sustainable PjBL has been framed around technical competence developed through real problem-solving situations (Mukunda Vani et al., 2021). Together, these studies support a mechanism in which a project supplies an organizing purpose for technical information.

4.5 From object knowledge to task-connected competence

That mechanism is particularly relevant to tools and equipment. If instruction is organized only around definitions, students may remember names and functions without understanding when a tool should be selected or how it relates to a work sequence. A project can instead locate the tool within a chain of decisions: identifying the task, determining required resources, selecting equipment, checking safety, executing the operation, and evaluating the result. Vocational curriculum development studies emphasize these forms of alignment. Muhtar et al. (2025), for example, connect project objectives in welding with specific performance expectations and authentic assessment, while Haq et al. (2024) place practical products at the center of project-based vocational learning. Kang et al. (2024) similarly describe a learning-factory environment in which practical facilities support project-based subjects and convergence competencies. Although the present test does not observe actual tool use, the project logic is compatible with the type of contextual organization required for later workshop performance.

4.6 Consistency across heterogeneous starting points

The absence of a significant relation between baseline score and gain magnitude is an important secondary result. Initial scores varied from 32 to 68, yet improvement was not evidently concentrated among students at one end of that range. This pattern resonates with research on differentiated and heterogeneous vocational learning. Bakshi (2026) showed how a shared project structure can support

differentiated tasks aligned to common outcomes, while Canut-Montalva et al. (2025) documented substantial variation in how vocational students value different learning resources despite a general preference for practical activity. In a PjBLV culinary study, Asnur et al. (2025) reported a relatively consistent distribution of outcomes across ability levels. The present data cannot demonstrate that PjBL caused equity in learning opportunities, but they do show that positive gain was not limited to initially stronger or weaker students.

4.7 Heterogeneity was reduced neither conceptually nor statistically

It is equally important not to overstate this finding. Students did not converge to the same post-test level; scores still ranged from 56 to 92, and the strong correlation between baseline and post-test scores indicates that pre-existing differences largely persisted. The intervention was associated with common upward movement, not complete closing of performance gaps. This distinction is consistent with evidence that vocational classrooms contain meaningful diversity in readiness and learning experience. Bascuguin and Generoso (2026) emphasize uneven readiness and the value of authentic, repeated, feedback-rich practice in technical-vocational instruction, whereas Díaz-Lauzurica and Moreno-Salinas (2025) report that active learning can improve interest and commitment in heterogeneous VET groups. Goncalves (2024) further cautions against reducing progress to preferred learning-style categories, finding only weak or very weak associations between learning style and performance in a technical course. The implication is that PjBL can coexist with a continuing need for differentiated support.

4.8 Competence development beyond test scores

A major strength of the wider literature is that it broadens the outcomes associated with project-oriented vocational learning beyond achievement tests. PjBL in vocational high school has been linked with computational thinking, teamwork, project management, abstraction, algorithmic thinking, and generalization in an Internet-of-Things project context (Habibi et al., 2025). Regional-potential projects have produced higher 4Cs scores than a free-theme project condition (Wulansari et al., 2022), and STEM-PjBL has been related to 21st-century learning and innovation skills, although communication may remain a weaker dimension (Yusuf et al., 2023). Technology-supported PjBL has also been associated with student engagement and non-technical skills (Lamada et al., 2026), while the combination of PjBL and mobile learning has been linked to constructive, independent, collaborative, and contextual engagement processes (Sardi et al., 2025). These studies highlight an important boundary of the current evidence: the present dataset captures test-based competence only, so it cannot determine whether students also improved collaboration, autonomy, communication, or project-management skills.

4.9 Career relevance and employability-oriented learning

Vocational learning ultimately matters because competence must transfer beyond the classroom. Several studies in the supplied literature position PjBL around this transition. Li and Rohayati (2024) found positive relationships among project-based learning, assessment strategies, and graduate competence attainment within an outcome-based framework. Zhang and Yeoh (2026) reported that a career-focused PBL model embedding authentic career scenarios enhanced learning motivation and was associated with stronger learning initiative and vocational skills. Tsutsumi (2025) described a community-integrated mechatronics project in which hands-on prototyping, interdisciplinary teamwork, and authentic feedback were accompanied by gains in technical competence, engagement, and learner autonomy. Zhang and Li (2024) synthesize evidence that PBL can support practical communication

abilities in higher vocational English. These studies suggest that the long-term value of project work lies in linking disciplinary learning with contexts in which competence is actually used.

4.10 Indonesian vocational relevance

The findings also sit within a specifically Indonesian movement toward project-oriented vocational education. Ahmad et al. (2023) identified Indonesia as the most active country in their 2010-2022 bibliometric sample of vocational PjBL research. Mutiaraningrum et al. (2024b) report generally positive cognitive, affective, and behavioral attitudes toward mandatory PjBL among Indonesian vocational college students, while their companion study links classroom projects with entrepreneurial knowledge, opportunity recognition, and entrepreneurial intentions (Mutiaraningrum et al., 2024a). Kholifah et al. (2025) describe project planning, implementation, product development, and evaluation in an Indonesian vocational character-education context. Nofriansyah (2020) also proposed a vocational software-engineering model organized around problem definition, project planning, supported interaction, project creation, monitoring, and assessment. Together, these studies show that project work is being interpreted not as a single lesson technique but as an organizing architecture for competence-oriented learning.

4.11 Implementation quality is a necessary condition

A positive outcome should not imply that any activity labeled "PjBL" will produce the same result. The literature repeatedly identifies implementation conditions that can facilitate or constrain project work. González et al. (2026) found that leadership support, collaborative culture, resources, and professional development were central to PBL implementation in Chilean vocational secondary schools. Ealangov and Jamaludin (2024) reported that lecturer knowledge and attitudes were strongly related to PjBL implementation skills in community colleges. Hufnagl and Annen (2026) identified shortages of time and personnel as barriers to PBL in the German dual VET system, while Sidik et al. (2026) synthesized challenges including time constraints, student and teacher readiness, collaboration with industry or experts, and resource support. Related work on student-centered vocational teaching also emphasizes that active learning requires a shift from instructor dominance toward facilitation and learner involvement (Rafiq et al., 2023). These findings make the missing fidelity information in the present study more than a reporting detail: without it, successful replication cannot be specified.

4.12 Institutional and resource conditions

Practical vocational learning also depends on the environment in which projects are implemented. During the pandemic, students in English University Technical Colleges reported lost learning opportunities when practical courses depended on equipment and facilities that were no longer accessible (Deepthi & Exley, 2023). Research on technical education likewise identifies outdated equipment, preparation time, and connectivity as barriers to integrating contemporary methods and digital tools (Mančík et al., 2026). A systematic review of STEM-TVET integration identifies institutional support and pedagogical self-efficacy as enabling factors while also noting rigid curricula, limited resources, and technological constraints (Polatuly et al., 2026). At the organizational level, studies of career and technical education have linked deeper-learning opportunities with open, collaborative, ambitious school cultures (Malin et al., 2024). Thus, PjBL should be treated as an instructional system embedded in material and organizational conditions, not as a context-free treatment.

4.13 Technology-enhanced project work: promise without conflation

Recent studies increasingly integrate project-based learning with digital technologies. Hwang et al. (2026) found that a generative-AI-supported collaborative robot project condition outperformed

conventional collaborative robot project training on achievement and several higher-order thinking tendencies. Saputro and Budiarto (2026) reported stronger critical-thinking outcomes for flipped PjBL integrated with mock-up and augmented-reality media than for conventional instruction, and Hasan et al. (2026) reported advantages from augmented-reality simulation in automotive troubleshooting. Such results are promising, but they also show why the effect of "PjBL" cannot always be separated from the technologies and scaffolds bundled with it. The current study is useful in this respect because its outcome can be discussed without attributing gains to a digital layer that was not documented. Future work could test whether technology adds value beyond a well-designed non-digital project sequence.

4.14 The statistical strength of the pattern and the measurement question

The extremely large Cohen's dz requires careful interpretation. The effect is mathematically driven by a mean gain of 24.39 points combined with only 2.80 points of between-student variability in gain. This is why the manuscript gives priority to the raw change, confidence interval, and 31/31 positive trajectories. The regular score increments also raise a measurement question. If the assessment yields scores in coarse steps, individual change will naturally cluster. Vocational assessment scholarship is increasingly interested in frameworks that capture both what students know and what they can do (Baker & Ragavanis, 2025), and practical-skills studies emphasize authentic, repeated, feedback-rich performance (Bascuguin & Generoso, 2026). The present result is strong as a test-score pattern, but the instrument documentation is insufficient to determine how sensitively it represents real workshop competence.

4.15 From test-based competence to authentic performance

The next evidentiary step is therefore to pair cognitive assessment with direct performance. A structured workshop rubric could score task interpretation, tool identification, selection, pre-use inspection, safe handling, procedural accuracy, equipment care, and completion quality. Such an approach would align more closely with project-based vocational models that emphasize work-like performance. Rahim et al. (2025), for instance, evaluated a STEAM-PjBL model in fabrication and manufacturing in relation to technical competence, problem solving, design innovation, communication, teamwork, project management, and industry readiness. Pla-Campas et al. (2025) used real preschool contexts to examine perceived professional competence, and Muhtar et al. (2025) foreground authentic performance assessment in vocational welding curriculum design. These examples show how future automotive studies could move beyond test gain toward evidence of competent action.

4.16 Limits of causal inference

The central methodological limitation remains the one-group pre-post design. A very small p value indicates that the paired data are inconsistent with a null distribution of no systematic change under the statistical model; it does not establish that PjBL alone caused the change. Repeated exposure to assessment content, maturation, ordinary instruction, unrecorded co-interventions, or contextual events could contribute. The wider evidence base itself recognizes this need for stronger designs. Ibrahim (2025) identifies a scarcity of longitudinal research and comparative evidence against traditional pedagogies, while the systematic review by Sidik et al. (2026) shows substantial variation in PBL design. The present study should therefore be read as strong within-cohort evidence of change, not a comparative effectiveness trial.

4.17 A stronger next study

A rigorous follow-up would use at least one concurrent comparison class and a prospectively documented intervention. Cluster allocation at class level may be more feasible than individual randomization in school settings. Baseline equivalence should be reported, and the primary analysis could compare post-test performance while controlling for baseline score or model repeated measurements with class-level clustering where multiple classes are involved. The assessment should combine a validated knowledge measure with direct practical performance, and the project sequence should specify duration, group structure, task authenticity, teacher scaffolding, feedback checkpoints, equipment access, and fidelity criteria. A delayed assessment would test retention, while a transfer task would determine whether students can select and use tools in a novel automotive problem rather than only reproduce recently practiced content.

4.18 Implications for instructional design

For teaching practice, the current result supports three cautious implications. First, workplace-tools instruction is a plausible domain for project organization because tools can be taught as functional resources inside a meaningful technical task rather than as isolated objects. Second, the persistence of post-test heterogeneity means that a common project should be accompanied by targeted scaffolding for students who remain below desired competence levels. Third, assessment should distinguish improvement from mastery. A learner can gain substantially and still fail to reach a workshop-readiness threshold. The present dataset does not provide a formal mastery cut-off, so no pass/fail claim is made. Future courses should define criterion-referenced standards before instruction and report both continuous gain and the proportion of learners achieving the required standard.

4.19 Individual-level evidence as an analytical contribution

Most classroom evaluations of instructional change are summarized through group statistics, yet the present data illustrate why individual trajectories add substantive information. The same 24-point mean increase could theoretically arise from sharply different response patterns: a few students could improve dramatically while others remain unchanged, weaker students could improve while stronger students plateau, or the whole cohort could move upward by similar amounts. Fig. 1 rules out these very different interpretations for the observed class. Every line moves upward, and Fig. 3 shows that the size of those movements is tightly concentrated. This is not a new statistical method, but it is a more informative evidentiary practice for competence-oriented education. Vocational studies increasingly emphasize differentiated pathways, authentic tasks, and the varied conditions under which students engage with learning (Bakshi, 2026; Canut-Montalva et al., 2025). Reporting person-level change alongside aggregate effects makes it possible to ask whether an intervention's apparent success is broadly shared. In the present study, that question produces the paper's strongest empirical observation: improvement was universal within the recorded cohort even though final performance remained heterogeneous. This distinction between average improvement and universally positive individual trajectories constitutes the study's key analytical contribution and provides a testable proposition for controlled replication.

4.20 Practical implications for automotive instruction

For automotive instructors, the findings support using projects as a structure for integrating otherwise fragmented knowledge about workplace tools and equipment. A project can be designed so that students must justify why a particular tool is selected, compare alternatives, identify safety constraints, sequence use correctly, and explain how the tool contributes to completion of the technical

task. Such activities would operationalize the theory-practice connection emphasized in vocational PjBL studies without assuming that activity alone guarantees learning (Ali et al., 2025; Hamdani & Suherman, 2021). Formative checks should be placed at points where incorrect reasoning could become repeated practice. Students could, for example, be required to identify and inspect tools before use, explain their selection to peers, and receive feedback before moving to the next project stage. Because the post-test distribution remained wide, instructors should also use the pre-test diagnostically. Learners entering with weaker foundations may need additional demonstrations or guided practice, whereas stronger learners may benefit from more complex selection problems. Project work can provide a common context, but the scaffolding within that context should remain responsive to individual readiness.

4.21 Generalizability, retention, and transfer

The present findings are internally coherent but externally narrow. They come from one Grade X automotive class, one topic, and one immediate pre-post sequence. Generalization to other schools, regions, vocational specializations, age groups, or assessment formats therefore requires replication. This is especially important because PjBL effects are shaped by institutional resources, teacher preparedness, project design, and access to authentic equipment (Ealangov & Jamaludin, 2024; González et al., 2026; Hufnagl & Annen, 2026). A multi-class study could determine whether the unusually consistent gain pattern survives variation in teachers and learning environments. Longer follow-up is equally important. Immediate post-test improvement does not establish retention, and retained knowledge does not necessarily guarantee transfer to unfamiliar workshop tasks. The broader PjBL literature identifies long-term effectiveness as an underdeveloped area (Ibrahim, 2025). A stronger automotive evidence base should therefore distinguish three outcomes: immediate learning, delayed retention, and transfer. Demonstrating all three would provide a much stronger basis for claiming that project-oriented instruction develops durable workplace competence rather than short-term test performance.

4.22 Scientific contribution

The contribution of this study is therefore deliberately bounded but meaningful. It does not claim that PjBL is novel, universally effective, or causally superior. Instead, it documents an unusually coherent pattern in a foundational automotive competence: a heterogeneous cohort at baseline showed a large upward shift; all observed students improved; gains were tightly clustered; and gain magnitude was not associated with initial score. This person-level pattern strengthens the usual class-mean narrative and suggests a testable proposition for future research: a well-structured project may provide a common competence-building pathway across students with different starting points while leaving relative differences in final attainment intact. Testing that proposition under controlled conditions would advance the field beyond simple pre-post effectiveness claims.

CONCLUSION

Project-Based Learning implementation in Grade X Basic Automotive Engineering Work was followed by a substantial and highly consistent increase in test-based competence concerning workplace tools and equipment. Across 31 students, the mean score increased from 48.39 to 72.77, corresponding to a 24.39-point gain (95% CI 23.36-25.41). The most compelling feature was not the p value but the distribution of change: all 31 students improved, with gains confined to 20-28 points. Baseline and post-test scores remained strongly correlated, showing that relative differences persisted even as the entire observed cohort moved upward, while baseline score was not associated with gain magnitude.

This pattern supports PjBL as a promising competence-oriented framework for foundational automotive learning and aligns with vocational research emphasizing authentic tasks, theory-practice connection, learner engagement, and work-relevant competence. Nevertheless, the evidence remains associational. The absence of a comparison group, limited description of the PjBL sequence, lack of instrument validation information, and reliance on a test-based outcome prevent claims of causal superiority or complete workshop competence. A controlled replication should document implementation fidelity, use validated cognitive and practical-performance measures, predefine mastery criteria, and include delayed retention and transfer tasks. Within these boundaries, the present study contributes a distinctive person-level result: PjBL implementation coincided with a large upward shift shared by every observed learner despite heterogeneous starting scores. This consistent person-level pattern provides a hypothesis for controlled, performance-based replication rather than evidence of causal superiority.

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