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Consistent Individual Learning Gains Following Problem-Based Learning in Automotive Lighting and Signaling Systems: A One-Group Pretest-Posttest Study in Vocational Education

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ABSTRAK

Dikotomi antara ilmu agama (qauliyah) dan ilmu umum (kauniyah) masih menjadi masalah persisten dalam pendidikan Islam, menghasilkan lulusan dengan kepribadian terbelah. Penelitian ini bertujuan untuk menganalisis model pendidikan holistik-integratif yang diterapkan di Pondok Pesantren Modern Dzikir Al Fath, yang mensintesiskan sains modern dengan nilai-nilai keislaman melalui kerangka "Hoki dengan MAKAM". Menggunakan pendekatan kualitatif deskriptif dengan metode analisis isi terhadap skema visual dan dokumen pendukung, penelitian ini mengkaji integrasi elemen Masjid, Alam, Kampus, dan Manusia sebagai ekosistem pembelajaran terpadu. Temuan mengindikasikan bahwa: (1) integrasi ilmu dimungkinkan melalui penciptaan lingkungan belajar berbasis MAKAM yang menghilangkan sekat antara ruang kelas dan realitas kehidupan; (2) implementasi prinsip manajemen E3P dan metode Moving Class Mastery Learning (MCML) menunjukkan kontribusi positif terhadap akselerasi penguasaan kompetensi santri; dan (3) teknik habituasi karakter melalui tahapan Dipaksa-Terpaksa-Biasa-Luar Biasa diinterpretasikan memiliki peran signifikan dalam membentuk profil lulusan dengan keseimbangan keterampilan teknis dan spiritual. Penelitian ini menyimpulkan bahwa model Al Fath menawarkan solusi inovatif bagi tantangan pendidikan Islam kontemporer, serta berpotensi berkontribusi pada pengembangan teori dan praktik pendidikan integratif, meskipun generalisasi tetap perlu diuji melalui penelitian empiris kuantitatif lanjutan.

Keywords: *character education, holistic education, integrative education, Islamic education, knowledge integration*

ABSTRACT

The dichotomy between religious sciences (qauliyah) and general sciences (kauniyah) remains a persistent problem in Islamic education, producing graduates with split personalities. This study aims to analyze the holistic-integrative education model implemented at Pondok Pesantren Modern Dzikir Al Fath, which synthesizes modern science with Islamic values through the "Hoki dengan MAKAM" framework. Using a descriptive qualitative approach with content analysis methods on visual schemes and supporting documents, this research examines the integration of Mosque, Nature, Campus, and Human elements as a unified learning ecosystem. The findings indicate that: (1) knowledge integration is achievable through the creation of a "MAKAM"-based learning environment that eliminates barriers between classroom instruction and lived reality; (2) the implementation of E3P management principles and Moving Class Mastery Learning (MCML) methods shows a positive contribution to accelerating students' competency mastery; and (3) the character habituation technique through the stages of "Forced-Compelled-Habitual-Extraordinary" is interpreted to have a significant role in shaping graduate profiles with balanced technical and spiritual skills. This study concludes that the Al Fath model offers an innovative solution to contemporary Islamic education challenges, and has the potential to contribute to the development of integrative educational theory and practice, although generalization still needs to be tested through further quantitative empirical research.
Kata kunci: pendidikan holistik, pendidikan integratif, pendidikan Islam, integrasi ilmu, pendidikan karakter

INTRODUCTION

Vocational education is expected to develop knowledge that can be used in occupationally meaningful situations rather than retained as isolated facts. This expectation is increasingly important in technical fields where learners must reason through open-ended tasks, adapt to changing technologies, and connect conceptual knowledge with action. Dreher (2025), for example, argues that the growing use of artificial intelligence in technical work increases the need for learning formats oriented toward open-ended problem solving, while a systematic review of robotics in vocational education shows that learning models and technologies shape cognitive, psychomotor, and affective outcomes in ways that should remain aligned with industry needs (Setyawan et al., 2025). Related career-focused project-based work likewise suggests that authentic occupational scenarios can strengthen motivation, initiative, and vocational skill development (Zhang & Yeoh, 2026). These developments reinforce a central premise of vocational pedagogy: technical learning is strongest when students must use knowledge to interpret and resolve meaningful problems.

Automotive electrical systems provide a demanding context for this premise. A student who can name a relay, fuse, switch, lamp, connector, or grounding point has not necessarily developed the competence needed to diagnose why a lighting circuit fails. Effective performance requires integration of component knowledge, circuit logic, symptom interpretation, measurement, and decision making. Evidence from adjacent electrical and technical domains supports the importance of this integration. In an electric-circuit course for mechatronics students from varied academic backgrounds, a blended interactive and problem-based framework supported engagement and consistent course-learning-outcome achievement (Hassan et al., 2025). In electrical/electronic technology education, a problem-based intervention also improved engagement and practical performance on sequential wiring tasks from circuit identification through powering the completed circuit (Orji, 2025). Automotive lighting and signaling systems therefore offer an especially suitable setting for investigating whether a problem-centered learning sequence is accompanied by measurable progress in technical understanding.

Problem-Based Learning (PBL) is conceptually aligned with this setting because learning begins with a problem that must be interpreted before a solution can be justified. Students identify what is known, recognize information gaps, generate explanations, apply or seek relevant knowledge, and evaluate possible solutions, while the teacher functions as a facilitator rather than the sole source of answers. Vocational research has associated problem-based formats with higher-order thinking, collaboration, and active student involvement. Scaffolding integrated with PBL supported progressive higher-order thinking in geomatics learning (Sukatiman & Akhyar, 2020), while inquiry and PBL approaches in vocational education were examined as student-centered alternatives to traditional instruction and produced differences in learning outcomes related to learner involvement (Rafiq et al., 2023). Digital variants further indicate that PBL can be combined with design thinking, flipped learning, simulation, or e-learning without abandoning its problem-centered logic (Nordin et al., 2020; Novalinda et al., 2023; Wagino et al., 2025; Wang et al., 2023).

The empirical literature nevertheless cautions against treating PBL as a uniform exposure with a universally predictable effect. A Problem-Based Learning Factory model in welding education was reported as valid, practical, and effective, with an average learning-outcome increase of 25% (Azman & Adri, 2025). A one-group pretest-posttest study of PBL assisted by mobile augmented reality in air-conditioning technology reported an average normalized gain of 0.70 among 30 vocational students (Hidayat et al., 2025). In a larger quasi-experimental study, problem-based intervention improved engagement and practical skills among 143 electrical/electronic technology students (Orji, 2025). Automotive evidence is also emerging: PBL integrated with e-learning was associated with strong engagement in problem-solving activities and perceived improvement in critical thinking among automotive engineering students (Wagino et al., 2025). These studies converge on the potential of problem-centered learning, yet they differ substantially in domain, digital support, sample, outcome measure, and design strength.

That heterogeneity has two implications for the present study. First, gains reported in one technical context cannot simply be transferred to another. Second, average improvement may conceal whether learners with different starting points experience the intervention similarly. This issue is not hypothetical. Hassan et al. (2025) explicitly examined a technically diverse cohort, while Nordin et al. (2020) compared high- and low-self-regulated TVET learners and found that ePBL combined with design thinking fostered collaboration across both groups. Wen and Sumettikoon (2024) further showed in vocational undergraduate education that instructor assistance and student motivation can shape relationships involving PBL and academic performance. Together, these studies suggest that learner characteristics and instructional support may influence how problem-centered learning operates, making individual-level change an important complement to class-level averages.

The distinction between problem-based and project-based learning is also important when interpreting the supplied literature. Several recent technical and vocational studies use the acronym PBL for project-based learning rather than Problem-Based Learning. These studies are relevant as evidence for the broader movement toward active, authentic learning, but they should not be treated as direct tests of the same pedagogy. Project-based studies have reported improved vocational achievement in controlled or quasi-experimental settings (Giatman & Mukhaiyar, 2025; Isa & Azid, 2021; Leksono Edy et al., 2020), but they also reveal variation in student response. In power electronics, for instance, two project groups differed in their success with problem identification, simulation, and hardware integration (Aishwarya et al., 2024), while a combined flipped-classroom and project-based format improved outcomes at some educational levels but not at the master's level (Köpeczi-Bócz, 2024). Such variability strengthens the case for examining who improves, not only whether the mean changes.

Within the supplied literature set, no study directly evaluates Problem-Based Learning for automotive lighting and signaling systems while simultaneously characterizing every student's paired learning trajectory. The available evidence is instead distributed across welding, air conditioning, geomatics, electrical/electronic technology, mechatronic circuits, digital vocational learning, and automotive e-learning (Azman & Adri, 2025; Hassan et al., 2025; Hidayat et al., 2025; Orji, 2025; Sukatiman & Akhyar, 2020; Wagino et al., 2025). This creates a defensible research gap: the question is not whether PBL is novel as a general method, but whether a problem-based sequence in a specific automotive electrical topic is followed by improvement that is both large at the class level and consistent across learners with markedly heterogeneous baseline achievement.

The study is therefore guided by three linked research questions. First, is there a statistically significant difference between pre-test and post-test scores following PBL-based instruction in automotive lighting and signaling systems? Second, what is the magnitude of the within-student change when expressed as raw gain, standardized change, and normalized gain? Third, how consistently is improvement distributed across individual students with different initial achievement levels? The primary hypothesis is that post-test scores will exceed pre-test scores. The substantive argument is stronger: if the learning pattern is genuinely broad, positive gains should appear across the class rather than being concentrated among a small subset of high responders.

The analytical framing deliberately separates statistical significance, educational magnitude, and consistency. Statistical testing evaluates whether the paired difference is compatible with a null mean change; effect-size and normalized-gain analyses characterize magnitude; and trajectory analysis reveals the direction and spread of individual responses. This distinction is especially useful in light of prior vocational studies that have used different outcome frameworks, including normalized gain (Hidayat et al., 2025), multivariate analysis of practical skills and engagement (Orji, 2025), course-learning-outcome monitoring across semesters (Hassan et al., 2025), and structural modeling of engagement-related constructs in automotive PBL-e-learning (Wagino et al., 2025). No single metric captures the full instructional pattern.

The contribution is also bounded by the design. The available dataset contains one class measured before and after the recorded PBL implementation, but no comparison group. Stronger controlled designs in related vocational research have compared experimental and contrast conditions or adjusted post-test differences for baseline performance (Giatman & Mukhaiyar, 2025; Isa & Azid, 2021; Orji, 2025). The present study cannot make the same causal claim. Its value lies instead in transparent characterization of within-student change: the size of the shift, the robustness of the inference to non-normal gains, and the degree to which improvement is shared across a heterogeneous cohort.

Accordingly, the purpose of this study was to evaluate changes in learning outcomes on automotive lighting and signaling systems following Problem-Based Learning among Grade XI Light Vehicle Engineering students, with particular emphasis on the magnitude and consistency of individual gains. By integrating descriptive statistics, paired parametric and nonparametric tests, effect-size estimation, normalized gain, correlation, and individual trajectories, the study seeks to extend vocational PBL reporting beyond a class-average result and to provide a disciplined basis for subsequent controlled research on technical diagnostic learning.

METHODS

2.1 Study design

The study was analyzed as a one-group pretest-posttest design. Each participant contributed two observations: a pre-test score representing achievement before the focal PBL-based instruction and a post-test score representing achievement after the instructional sequence. The paired structure of the data permits direct estimation of within-student change. This design is appropriate for an initial classroom evaluation because each learner functions as his or her own temporal reference point, thereby reducing between-student variability when estimating the mean change.

The design does not include a control or comparison class. Consequently, the analysis is intended to establish the presence, magnitude, and consistency of change following the intervention rather than to provide definitive causal evidence that PBL alone generated that change. This distinction is maintained throughout the manuscript. The study can show that performance improved after the PBL implementation and that the pattern was strong across individual students; it cannot independently rule out all competing explanations for the observed pre-post difference.

2.2 Participants and instructional context

The dataset comprised 23 students identified as Grade XI TKR (Teknik Kendaraan Ringan; Light Vehicle Engineering). The instructional subject was PKKR (Perawatan Kelistrikan Kendaraan Ringan; Light Vehicle

Electrical Maintenance), and the focal content was the system of lighting and signaling lamps. The instructional model was identified as Problem-Based Learning. All 23 students had both a pre-test and a post-test score, producing a complete paired dataset with no missing score observations.

The available dataset does not record demographic characteristics, school identity, semester, intervention duration, number of instructional meetings, group composition, or student-selection procedure. These characteristics are therefore not reconstructed or inferred. They should be supplied from the original instructional records before journal submission because they are necessary for complete reporting of context and external validity. For the same reason, the present draft does not assert a probability-sampling strategy or population-level representativeness beyond the observed class.

2.3 Instructional construct: Problem-Based Learning

The dataset explicitly identifies PBL as the learning model but does not provide a lesson plan or implementation-fidelity record. The intervention is therefore treated at the level supported by the source data: students learned the automotive lighting and signaling topic through a PBL approach. Conceptually, PBL is compatible with this technical domain because an instructional problem can require students to interpret a malfunction, identify relevant circuit elements, generate alternative fault explanations, and select a justified diagnostic or corrective pathway.

A complete final report should describe the exact classroom implementation, including the initiating problem scenario, sequence of student activities, teacher facilitation, use of wiring diagrams or components, group organization, duration of problem investigation, and form of solution presentation. Those details are essential for replication. They are not supplied in the score dataset and are therefore deliberately not fabricated in this initial manuscript. The statistical conclusions below concern learning outcomes associated with the recorded PBL implementation, independent of unverified procedural details.

2.4 Outcome measure

The outcome variable was the learning score recorded on a 0-100 scale. Pre-test scores were available for all students before the PBL learning sequence, and post-test scores were available for the same students afterward. The score file did not contain the test blueprint, number of items, item format, item-level responses, reliability coefficient, validity evidence, or minimum mastery criterion. Accordingly, the study analyzes observed score change but does not make unsupported claims about psychometric reliability, content validity, diagnostic subdomains, or mastery status.

In response to the author comment on assessment reporting, the analytical source files were rechecked. They do not document whether the achievement instrument consisted of multiple-choice items, diagnostic constructed-response items, or a combined theory–practice assessment, nor do they establish whether the pre-test and post-test used identical or parallel forms. These characteristics are therefore not inferred here and must be verified against the original assessment materials.

Before publication, the instrument section should be completed from the original assessment documentation. At minimum, the final manuscript should explain the relationship between test items and curriculum competencies, scoring rules, equivalence of pre-test and post-test forms if different forms were used, and evidence that the instrument adequately measured intended knowledge or problem-solving outcomes. If the same test was used twice, that fact should also be reported because repeated exposure may contribute to score change.

2.5 Data preparation and descriptive analysis

The spreadsheet was checked for completeness and paired correspondence. Twenty-three numbered student records were present, followed by spreadsheet-calculated totals and averages. Only the 23 student-level observations were treated as analytical cases; the total and average rows were excluded from inferential calculations. Pre-test and post-test scores were converted to numeric arrays, and an individual gain score was calculated as post-test minus pre-test.

Descriptive statistics included the mean, standard deviation, median, interquartile range, minimum, and maximum for pre-test, post-test, and gain. Individual gain frequencies were also calculated to assess whether improvement was concentrated at a particular level. Because a score of 100 represented the apparent maximum of the scale, normalized gain was calculated for descriptive purposes as (post-test - pre-test)/(100 - pre-test). This statistic expresses the proportion of the maximum possible improvement achieved by an individual, given the starting score. Normalized gain was used only as a supplementary descriptive measure and not as a substitute for paired inferential testing.

2.6 Inferential statistical analysis

The principal inferential analysis used a paired-samples t test comparing post-test and pre-test scores. The paired t statistic evaluates whether the mean of the within-student differences is different from zero. A two-sided significance threshold of alpha = .05 was used. The 95% confidence interval for the mean gain was calculated from the standard error of the paired differences using the t distribution with n - 1 degrees of freedom.

The normality assumption relevant to the paired t test concerns the distribution of difference scores rather than the separate pre-test and post-test distributions. The Shapiro-Wilk test was therefore applied to individual gains. Because the gain distribution showed evidence of non-normality, a Wilcoxon signed-rank test was additionally conducted as a nonparametric robustness check. Agreement between the parametric and nonparametric analyses would strengthen confidence that the conclusion does not depend on the normality assumption.

Within-student standardized change was quantified using Cohen's dz, calculated as the mean paired difference divided by the standard deviation of the paired differences. A small-sample corrected estimate was also considered using the usual Hedges-type correction to dz. Because effect-size labels can be misleading when interpreted mechanically, the standardized estimate was considered together with the raw mean gain, confidence interval, score range, and graphical distribution.

2.7 Analysis of consistency and heterogeneity

A central methodological feature of this study was the explicit analysis of individual trajectories. For each student, the direction and magnitude of change were inspected. The number and proportion of students with positive, zero, and negative gains were calculated. Gains were also summarized at thresholds of at least 15, 20, 25, 30, and 35 points. These thresholds are descriptive and correspond to the discrete gain values observed in the dataset; they are not presented as externally validated mastery categories.

The association between pre-test and post-test performance was examined using Pearson correlation to characterize rank consistency across measurement occasions. A strong positive association would indicate that baseline differences remained visible after instruction even when the entire distribution shifted upward. Such a pattern is educationally informative: broad improvement does not necessarily imply elimination of achievement differences.

Four visualizations were generated. A paired trajectory plot displayed every student's pre-test and post-test score. A box-and-point plot summarized the distributional shift. A gain-frequency plot showed the number of students at each observed gain level. Finally, a scatter plot of pre-test against post-test scores with an identity line visually assessed whether individual post-test values lay above the no-change line.

2.8 Reporting boundaries and missing design information

The analysis is restricted to the information supported by the score file and the identified instructional context. No demographic covariates, attendance data, prior-grade indicators, classroom observation data, control-group scores, delayed retention test, or item-level assessment data were available. Therefore, subgroup comparisons, multivariable causal modeling, fidelity analysis, mastery-rate analysis, and retention inference were not attempted.

Information on institutional ethics review and participant consent was not present in the dataset. These elements must be completed from the original research documentation in the final submission. Their absence from the score file should not be interpreted as evidence that such procedures were not undertaken; it only means that they cannot be documented from the present analytical source. This reporting discipline is important because a rigorous manuscript should distinguish measured findings from contextual information that still requires author verification.

RESULTS AND DISCUSSION

3.1 Results

3.1.1 Baseline achievement and post-test performance

All 23 paired observations were complete. Pre-test performance was low and heterogeneous. The mean pre-test score was 36.09 (SD = 12.43), with a median of 35.00. Scores ranged from 10 to 70, and the interquartile range extended from 30 to 40. The 60-point spread between the lowest and highest baseline score indicates that students entered the learning sequence with substantially different levels of measured achievement.

Post-test performance shifted upward. The mean post-test score was 62.83 (SD = 15.51), and the median was 65.00. Scores ranged from 35 to 85, with an interquartile range from 50 to 75. Thus, both the center and the lower boundary of the score distribution increased. The minimum score rose from 10 to 35, while the maximum increased from 70 to 85. Importantly, the post-test distribution did not simply compress around a common value; variability remained substantial, showing that students continued to differ in final achievement even though the class moved upward overall.

The difference between the two medians was 30 points, while the difference between the means was 26.74 points. The similarity of these indicators supports the interpretation that the upward shift was not caused solely by an extreme observation. Figure 1 illustrates the displacement of the whole distribution. The post-test box is positioned markedly above the pre-test box, and the individual points show comparatively little overlap at the central portions of the two distributions.

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

Measure	n	Mean	SD	Median	Q1-Q3	Min-Max
Pre-test	23	36.09	12.43	35.00	30-40	10-70
Post-test	23	62.83	15.51	65.00	50-75	35-85
Gain	23	26.74	7.17	25.00	20-35	15-35

Note. Gain = post-test minus pre-test. Q1–Q3 = interquartile range.

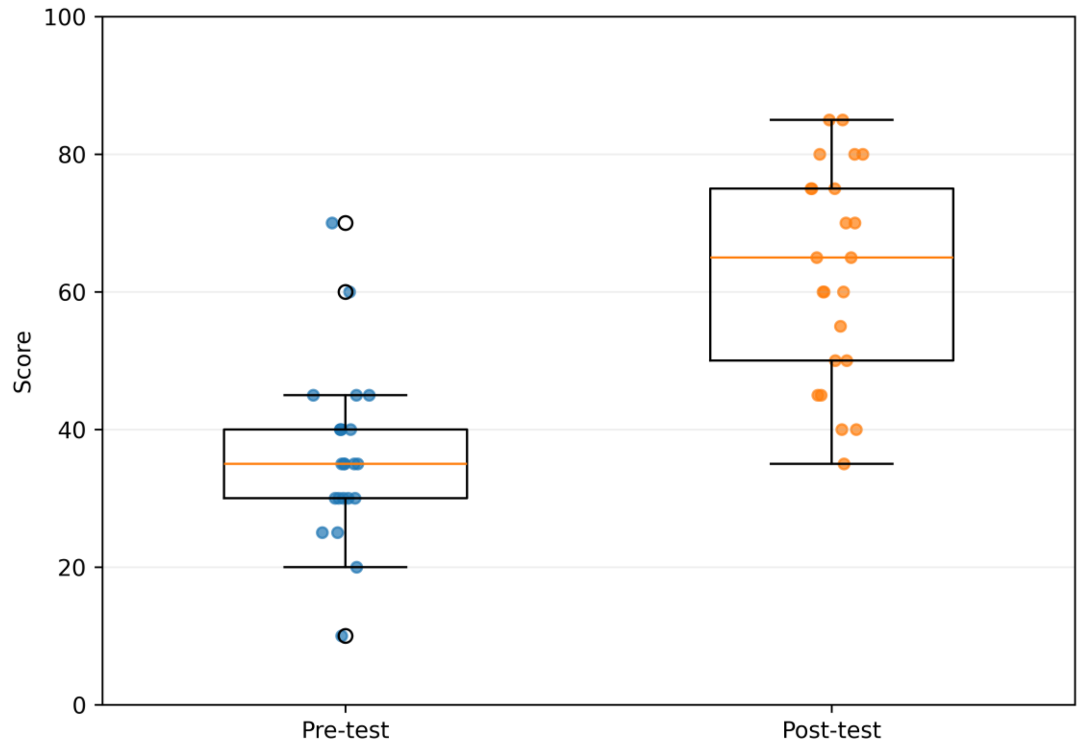

Fig. 1. *Distributional shift in learning scores. Boxplots summarize the pre-test and post-test distributions, with jittered points representing individual students.*

3.1.2 Magnitude of individual learning gains

The mean individual gain was 26.74 points (SD = 7.17), with a median gain of 25 points. Gains ranged from 15 to 35 points. The first quartile was 20 points and the third quartile was 35 points. Therefore, at least three quarters of the class improved by 20 points or more, and one quarter improved by 35 points.

The observed gains took five discrete values. Three students improved by 15 points, four by 20 points, five by 25 points, four by 30 points, and seven by 35 points. Put differently, all 23 students improved by at least 15 points; 20 students (87.0%) improved by at least 20 points; 16 students (69.6%) improved by at least 25 points; 11 students (47.8%) improved by at least 30 points; and seven students (30.4%) improved by 35 points. No student had a zero or negative change.

This distribution is central to the research argument. If the mean improvement had been generated by a small set of unusually large gains, one would expect a mixture of positive, neutral, and possibly negative individual changes. Instead, every line in Figure 2 slopes upward from pre-test to post-test. The pattern therefore represents a class-wide positive shift rather than an average that masks deterioration among part of the cohort.

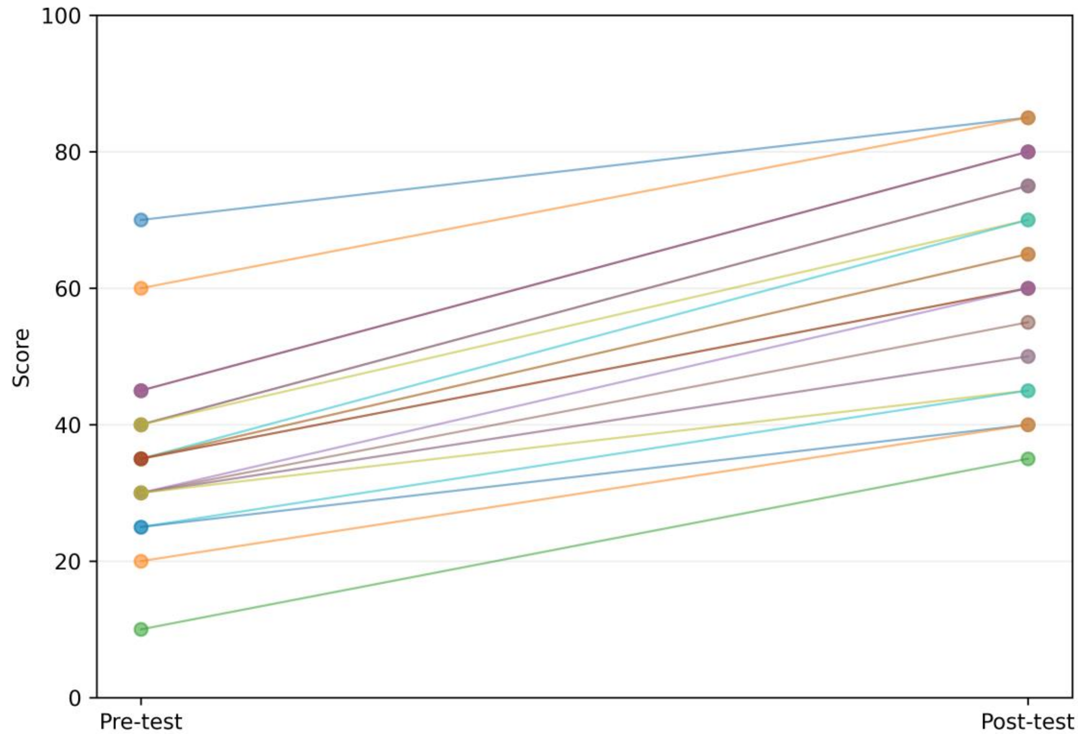

Fig. 2. *Individual pre-test to post-test trajectories. Each connected pair represents one student; all 23 trajectories move upward.*

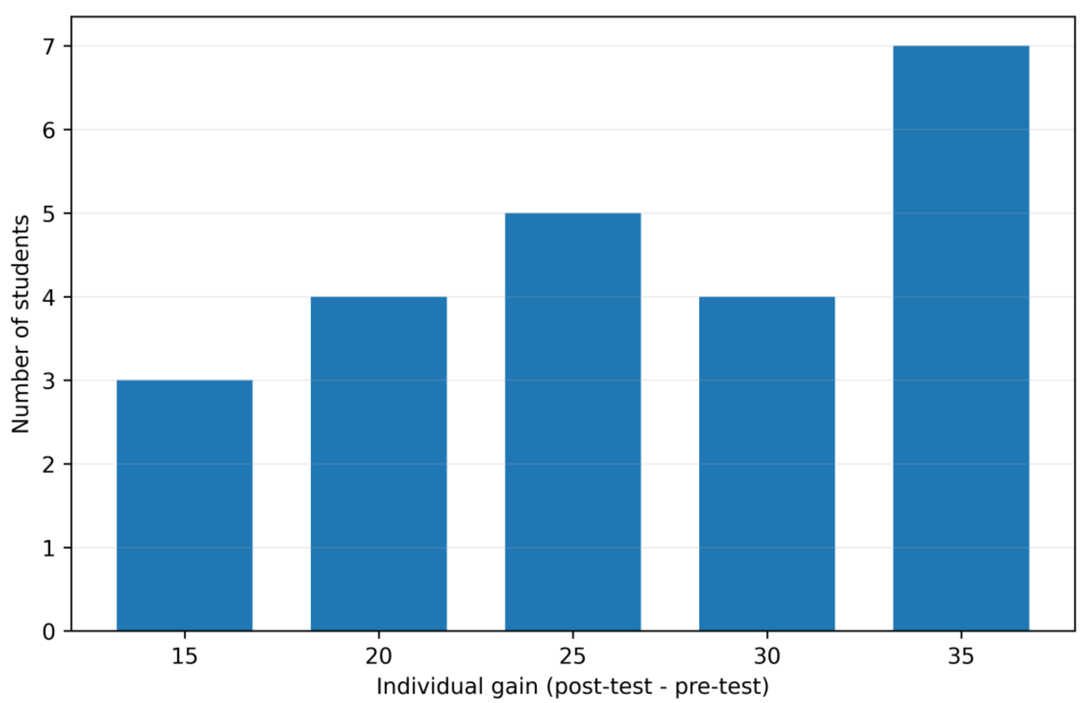

Fig. 3. *Frequency distribution of individual learning gains. Gains occurred at 15, 20, 25, 30, and 35 points, with no zero or negative change.*

3.1.3 Paired inferential test

The paired-samples t test showed that post-test scores were significantly higher than pre-test scores, $t(22) = 17.89$, $p < .001$. The estimated mean difference was 26.74 points, and its 95% confidence interval ranged from 23.64 to 29.84 points. The interval lies far above zero and is narrow relative to the observed mean difference, indicating that the estimated average improvement is both large and statistically precise for this class.

The standardized within-student effect size was Cohen's $d_z = 3.73$. After applying a small-sample correction, the estimate remained approximately 3.60. These values indicate that the mean change was several standard deviations of the difference-score distribution. Because standardized effect sizes in one-group pre-post designs can be influenced by design characteristics and do not by themselves establish causality, the raw change of approximately 27 points and the universal direction of improvement provide essential context for interpretation.

The Shapiro-Wilk test applied to the difference scores yielded $W = 0.879$, $p = .0098$, indicating evidence against a normal difference distribution. This result is understandable given that gains occurred at only five discrete values. To ensure that the primary conclusion was not an artifact of the parametric assumption, a Wilcoxon signed-rank test was conducted. The Wilcoxon statistic was 0, with $p < .001$, again indicating a systematic positive shift. The concordance of the paired t test and Wilcoxon analysis supports a robust conclusion that achievement increased between measurements.

Table 2. *Inferential and effect-size summary of the paired pre-test–post-test analysis.*

Analysis	Estimate / statistic	95% CI	p value	Interpretive role
Mean paired gain	26.74 points	23.64-29.84	-	Raw magnitude of change
Paired-samples t test	$t(22) = 17.89$	23.64-29.84	$< .001$	Primary paired comparison
Shapiro-Wilk on gains	$W = 0.879$	-	.0098	Difference scores non-normal
Wilcoxon signed-rank	$W = 0$	-	$< .001$	Nonparametric robustness check
Cohen's dz	3.73	-	-	Within-student standardized change

Analysis	Estimate / statistic	95% CI	p value	Interpretive role
Small-sample corrected dz	3.60	-	-	Bias-adjusted standardized change
Mean normalized gain	0.438	-	-	Supplementary descriptive progress
Pre-test-post-test correlation	r = .891	-	< .001	Persistence of relative rank
Positive individual gains	23/23 (100%)	-	-	Consistency of direction

3.1.4 Normalized gain

Individual normalized gains, calculated relative to the maximum score of 100, had a mean of 0.438 (SD = 0.149) and a median of 0.462. Values ranged from 0.200 to 0.636. Sixteen students had normalized gains between 0.30 and 0.70, while seven had values below 0.30; none reached 0.70 or above. These categories are reported descriptively rather than as definitive indicators of instructional quality because normalized gain is sensitive to baseline score and should not replace direct paired comparisons.

The normalized-gain results add an important nuance. The raw improvement was large and universal, but the class did not approach the ceiling of the scoring scale. The highest post-test score was 85, and the post-test mean remained 37.17 points below the nominal maximum of 100. Therefore, the intervention was followed by substantial learning progress but not complete attainment of all possible score points. This distinction prevents an overstatement that PBL brought the class to full mastery. A minimum mastery criterion was not provided in the dataset, so no mastery-rate claim is made.

3.1.5 Baseline heterogeneity and persistence of rank differences

Pre-test and post-test scores were strongly positively associated, Pearson $r = .891$, $p < .001$. Students with relatively high pre-test scores generally remained among the higher scorers at post-test, while students with lower baselines tended to remain lower in relative rank despite improvement. This finding is visible in Figure 4, where the points cluster along an upward association while remaining above the identity line.

The combined pattern is educationally informative. PBL implementation was followed by improvement across the entire class, but it did not erase initial differences. For example, the student with the lowest pre-test score improved from 10 to 35, while a student beginning at 70 improved to 85. Several students beginning at 40-45 reached 75-80. Thus, students at low, middle, and high starting levels all exhibited positive gains, but the final distribution remained heterogeneous.

This result supports a cautious interpretation of inclusiveness. The evidence shows broad benefit in the sense that no learner declined and every learner gained at least 15 points. It does not show complete convergence of achievement. The post-test standard deviation (15.51) was in fact larger than the pre-test standard deviation (12.43), indicating that absolute dispersion did not shrink. PBL in this dataset was therefore associated with a general upward movement rather than equalization of all learners to a common performance level.

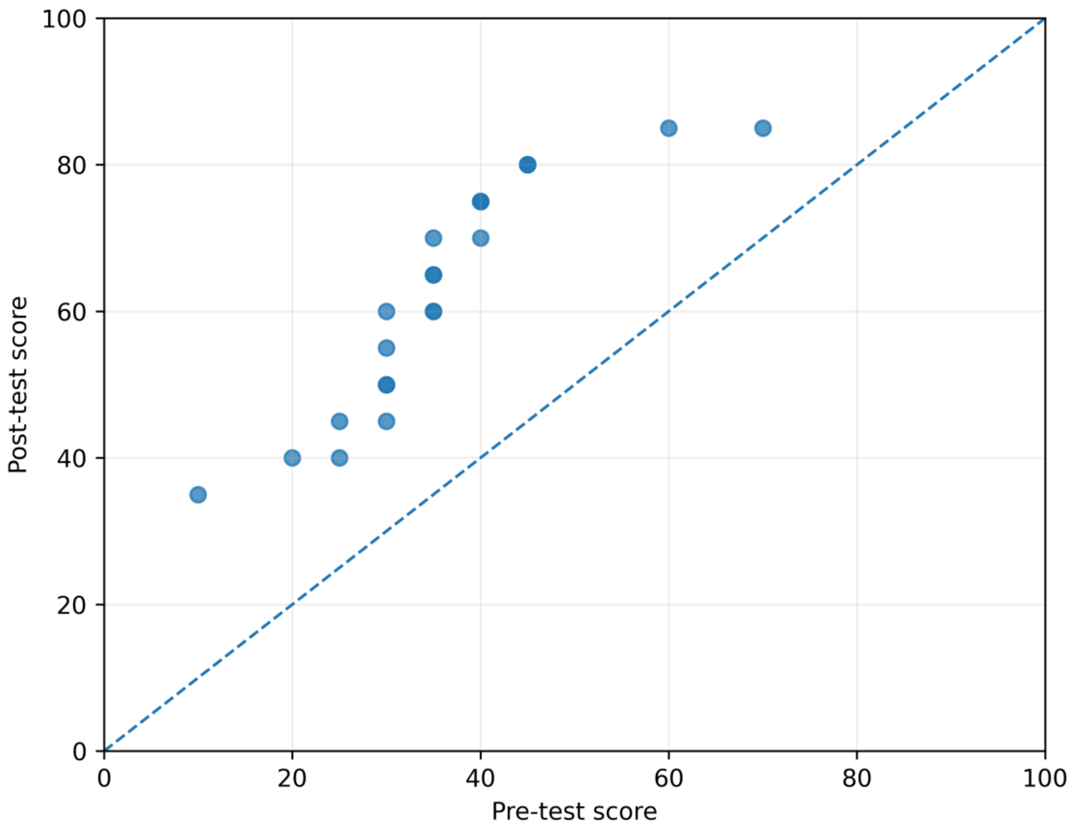

Fig. 4. *Relationship between baseline and post-test performance. The dashed identity line represents no change; every observed point lies above the line.*

3.1.6 Visual synthesis of the learning pattern

The four figures provide complementary views of the same phenomenon. Figure 2 emphasizes direction: every paired trajectory rises. Figure 1 emphasizes the distributional shift: both central tendency and the lower portion of the distribution move upward. Figure 3 emphasizes magnitude: gains are distributed between 15 and 35 points, with the largest frequency at 35 points. Figure 4 emphasizes baseline heterogeneity: students remain ordered to a considerable extent by initial achievement, yet all observed post-test points lie above the identity line.

Taken together, these visualizations show why individual-level analysis contributes information beyond a mean comparison. The mean gain of 26.74 points is statistically persuasive, but the trajectory plot establishes that the improvement was not achieved at the cost of declines among selected students. At the same time, the baseline-post-test scatter guards against a different overinterpretation: universal positive change should not be equated with elimination of prior achievement differences.

The quantitative evidence therefore supports three simultaneous statements. First, learning outcomes increased substantially after the recorded PBL implementation. Second, the improvement was unusually consistent at the level of individual students. Third, the class remained heterogeneous after instruction, indicating scope for further differentiated support and continued learning.

3.2 Discussion

3.2.1 Principal findings

The study examined learning outcomes in automotive lighting and signaling systems among 23 Grade XI Light Vehicle Engineering students following Problem-Based Learning. Three findings define the result. First, mean achievement increased by 26.74 points, from 36.09 to 62.83, and the change remained statistically significant under both paired parametric and nonparametric tests. Second, the standardized within-student change was very large. Third, every student improved, with no zero or negative gain. The result therefore combines statistical strength with unusual directional consistency at the individual level.

The magnitude is broadly compatible with evidence that problem-centered learning can improve outcomes in vocational and technical contexts, although direct numerical comparison would be inappropriate because designs and measures differ. Azman and Adri (2025) reported an average 25% increase after a Problem-Based Learning Factory model in welding, Hidayat et al. (2025) reported a high average N-Gain of 0.70 with PBL assisted by mobile augmented reality in air-conditioning technology, and Orji (2025) found significant gains in engagement and practical wiring skills under a quasi-experimental problem-based intervention. In automotive higher education, Wagino et al. (2025) likewise linked PBL-e-learning with strong problem-solving engagement and critical-thinking perceptions. The present study adds a narrower but analytically distinctive observation: improvement was positive for all 23 paired cases rather than being inferred only from an aggregate mean.

3.2.2 Interpreting the result in the context of vocational problem solving

The result is pedagogically plausible given the structure of automotive lighting and signaling systems. A functioning circuit depends on coordinated relations among the power source, protective devices, conductors, switches, relays or control units, lamps, connectors, and ground paths. Diagnostic reasoning therefore requires students to move between an abstract circuit representation and a concrete symptom. This resembles the practical-sequence logic examined by Orji (2025), where electrical/electronic technology students performed linked tasks from identifying circuit positions through inspection and powering, and the circuit-learning context described by Hassan et al. (2025), where interactive problem-based activities were used to support conceptual, analytical, and practical learning across students with different academic backgrounds.

Problem-Based Learning can make these relationships instructionally salient because a technical problem creates a reason to retrieve, connect, and test knowledge. In vocational geomatics, scaffolding combined with PBL was associated with progressively higher levels of cognitive performance and higher-order thinking (Sukatiman & Akhyar, 2020). Rafiq et al. (2023) similarly positioned PBL as a student-centered approach in which learners actively adapt and solve problems, while Nordin et al. (2020) showed that ePBL integrated with design thinking could foster collaboration among both high- and low-self-regulated TVET learners. These studies do not establish the mechanism operating in the present class, but they support the plausibility that structured problem engagement can organize technical learning around use rather than recall.

The present score data, however, do not directly measure diagnostic reasoning, collaboration, motivation, or transfer to workshop performance. That boundary matters because several studies in the supplied literature assessed broader constructs: Novalinda et al. (2023) examined critical thinking, collaboration, communication, creativity, and learning outcomes; Wagino et al. (2025) assessed expectations, perceived quality, value, satisfaction, engagement, and critical-thinking perceptions; and Orji (2025) included observable practical-skill tasks. The current findings should therefore be interpreted as evidence of cognitive achievement change. A stronger follow-up study would test whether the same students can transfer that knowledge to fault diagnosis on real or simulated vehicle circuits.

3.2.3 Why individual trajectories strengthen the contribution

A distinctive analytical strength of this study is the explicit attention to individual trajectories. Mean comparisons are efficient summaries, but they cannot show whether an intervention benefits students evenly. The supplied vocational literature demonstrates why this distinction matters. Nordin et al. (2020) explicitly compared learners with high and low self-regulation, Hassan et al. (2025) emphasized challenges arising from diverse academic backgrounds, and Wen and Sumettikoon (2024) identified instructor assistance and student motivation as factors that shape relationships involving PBL and academic performance. Variation among learners is therefore not peripheral to vocational pedagogy; it is part of the instructional problem itself.

In the present class, the paired trajectory plot makes the response pattern immediately visible: all 23 lines move upward. This is analytically different from observing a favorable class mean. Related project-based research illustrates the possibility of uneven response: Aishwarya et al. (2024) reported contrasting outcomes between student sets in a power-electronics project, while Köpeczi-Bócz (2024) found that a combined flipped and project-based approach improved motivation and achievement at bachelor and higher-vocational levels but not significantly at the master's level. Although project-based learning is pedagogically distinct from Problem-Based Learning, these studies reinforce the broader point that active-learning effects can vary across learners and contexts. The universal direction observed here is therefore a meaningful descriptive feature.

Universal improvement should not be confused with equalization. Post-test scores still ranged from 35 to 85, and the strong pre-post correlation indicates that students largely retained their relative positions. The post-test standard deviation was also higher than the pre-test standard deviation. PBL in this cohort was thus associated with broad upward movement rather than convergence to a common level. This interpretation is consistent with the need for adaptive support emphasized in heterogeneous technical cohorts (Hassan et al., 2025) and with evidence that learner regulation and instructional design can condition participation patterns (Nordin et al., 2020).

3.2.4 Magnitude, statistical significance, and educational significance

The paired t statistic was large because the mean gain was substantial relative to the variability of the gain scores, and the 95% confidence interval placed the mean improvement at approximately 24-30 points. The Wilcoxon signed-rank test reached the same conclusion despite evidence that the gain distribution was non-normal. Concordance between these two analyses is important because the gains occurred at only five discrete values. The result is therefore not dependent on a single distributional assumption.

Educational significance is supported by the raw pattern as well as the p value. The mean gain exceeded one quarter of the 0-100 scale, the median moved from 35 to 65, and the smallest individual increase was 15 points. These changes are more interpretable for educators than statistical significance alone. Comparison with prior studies should nonetheless remain qualitative. Azman and Adri (2025) reported a 25% average increase under a welding PBLF model, while Hidayat et al. (2025) reported an average N-Gain of 0.70 in an augmented-reality-assisted PBL course. Their instruments, learners, content, and interventions differ from the present study, so the numerical values should not be treated as effect-size equivalents.

Cohen's dz of 3.73 is exceptionally large, but its meaning is specific to the within-student standardization used here. When nearly every participant changes in the same direction and difference scores have limited dispersion, dz can become very large. It does not establish how much better PBL would perform than an alternative method. Studies with comparison groups, such as the quasi-experimental work of Orji (2025) and the controlled project-based studies of Giatman and Mukhaiyar (2025) and Isa and Azid (2021), address a different causal question. The present effect size should therefore be read as a standardized description of within-class change, not as a between-method superiority estimate.

3.2.5 The meaning of heterogeneous baseline achievement

The pre-test range of 10-70 indicates pronounced heterogeneity in baseline achievement. Such dispersion is instructionally consequential because students enter the same technical problem with different levels of circuit knowledge, confidence, and readiness. Hassan et al. (2025) identified comparable challenges when teaching electric circuits to students from varied academic entry backgrounds. Nordin et al. (2020) likewise demonstrated that self-regulation can differentiate how TVET learners participate in collaborative problem-based environments. The present cohort therefore provides a useful setting for asking whether positive change can extend across a broad baseline distribution.

The data show that lower-, middle-, and higher-scoring students all improved, but relative rank remained strongly preserved. This combination suggests that PBL may be compatible with heterogeneous classes without automatically eliminating achievement differences. The finding is consistent with a broader literature in which learner characteristics and support remain consequential even under active-learning models. Wen and Sumettikoon (2024), for example, found that instructor assistance mediated relationships involving PBL and academic outcomes in vocational education, while Rafiq et al. (2023) reported differences in outcomes associated with learner involvement. Improvement and equity are therefore related but distinct dimensions of instructional quality.

For practice, this pattern argues for differentiated scaffolding within a common problem context. Students with weaker prerequisite knowledge may need explicit support in reading wiring diagrams, tracing current paths, or connecting component symbols with physical parts. Learners with stronger baselines can be challenged with competing fault hypotheses, multi-fault scenarios, or justification of alternative diagnostic sequences. Scaffolding is particularly relevant because Sukatiman and Akhyar (2020) reported progressive development of vocational higher-order thinking under a scaffolding-PBL model. Digital representations may also support differentiation; Wang et al. (2023) reported that finite-element visualizations integrated with PBL improved vocational students' understanding and learning initiative in a technical experiment.

3.2.6 Normalized gain and the distinction between progress and mastery

The mean normalized gain of 0.438 indicates that students achieved, on average, about 44% of the improvement available between their baseline score and the nominal maximum of 100. This provides a baseline-adjusted descriptive view of progress and is directly comparable in form, though not in magnitude, with the N-Gain approach used by Hidayat et al. (2025) in vocational air-conditioning technology. Their reported mean N-Gain of 0.70 was higher, but differences in content, assessment, technology support, sample, and intervention design prevent a direct inference that one instructional model was more effective than the other.

The normalized-gain distribution also prevents an overly strong mastery claim. No student reached an N-Gain of 0.70 or above in the present dataset, the highest post-test score was 85, and the post-test mean remained below 70. Because the dataset does not provide an institutional minimum mastery criterion, the proportion of students attaining formal competence cannot be determined. Progress and mastery are different claims: the former is demonstrated by paired change, whereas the latter requires a defined threshold and evidence that the assessment validly represents the intended competency.

This distinction is especially important in vocational education, where written achievement is only one layer of competence. Orji (2025) measured practical electrical tasks in addition to engagement, and

Giatman and Mukhaiyar (2025) assessed theoretical and practical skills in blended project-based computer-network education. Setyawan et al. (2025) similarly concluded from a systematic review that technology-supported vocational learning can affect cognitive, psychomotor, and affective domains. Future automotive studies should therefore combine cognitive tests with wiring-diagram interpretation, structured diagnostic cases, and workshop performance to determine whether learning gains transfer to occupationally relevant action.

3.2.7 Causal interpretation and design limitations

The largest limitation is the absence of a control group. A one-group pretest-posttest design can establish that the measurement sequence changed after the instructional period, but it cannot isolate PBL from all concurrent influences. This limitation is particularly clear when the study is contrasted with related quasi-experimental research. Orji (2025) compared intervention and control groups using MANCOVA, Giatman and Mukhaiyar (2025) used a nonequivalent control-group design with baseline adjustment in blended project-based learning, and Isa and Azid (2021) compared treatment and control groups in secondary TVET project-based learning. Those designs permit stronger counterfactual inference than the present dataset.

Several alternative explanations remain plausible, including ordinary curriculum exposure, repeated testing, additional study, teacher feedback, or other learning activities occurring between measurements. If identical pre-test and post-test forms were used, familiarity with the test could also contribute. The supplied data do not allow these possibilities to be separated. Consequently, statements such as 'PBL caused a 26.74-point improvement' or 'PBL was superior to conventional teaching' would exceed the evidence.

The appropriate conclusion is therefore associative and temporally bounded: achievement increased following the recorded PBL implementation, and the increase was large and universal within the observed class. This discipline does not weaken the result; it clarifies exactly what the data establish. Controlled evidence from adjacent vocational contexts makes the hypothesis of a genuine instructional contribution plausible (Azman & Adri, 2025; Orji, 2025; Rafiq et al., 2023), but causal confirmation for automotive lighting and signaling systems requires a comparison condition.

3.2.8 Measurement limitations and information needed for replication

A second limitation concerns the assessment instrument. Only total pre-test and post-test scores were available, with no item-level responses, test blueprint, reliability coefficient, or validity evidence. The data therefore cannot reveal which subskills improved most, whether misconceptions persisted, or whether the test distinguished component knowledge from diagnostic reasoning. This limitation is consequential because vocational PBL studies often measure multiple constructs. Novalinda et al. (2023) assessed critical thinking, collaboration, communication, creativity, and learning outcomes, while Orji (2025) incorporated observable practical tasks. A richer outcome battery would better represent the intended competencies of automotive problem solving.

A third limitation is intervention documentation. The dataset identifies the class, subject, topic, and PBL model, but it does not specify duration, number of sessions, problem scenarios, group size, teacher prompts, practical equipment, or implementation fidelity. These details are essential because PBL is not a single standardized exposure. Digital and blended variants in the supplied literature differ substantially, including ePBL with design thinking (Nordin et al., 2020), PBL integrated with flipped computer-based instruction (Novalinda et al., 2023), mobile-augmented-reality-assisted PBL (Hidayat et al., 2025), and automotive PBL integrated with e-learning (Wagino et al., 2025). Replication therefore requires documentation of the actual instructional architecture.

A fourth limitation is sample scope. The cohort contains 23 students from one class, so the result should not be generalized automatically to other schools, teachers, grades, or automotive programs. Studies in the supplied literature range from small technical groups to samples exceeding 100 students, and several report that outcomes interact with learner characteristics or educational level (Hassan et al., 2025; Köpeczi-Bócz, 2024; Nordin et al., 2020). Multisite replication would be needed to determine whether the unusually consistent individual gains observed here are reproducible.

3.2.9 Implications for teaching automotive electrical systems

Despite these limitations, the observed pattern has practical implications for automotive electrical instruction. First, lighting and signaling systems are well suited to a problem-centered architecture because faults can be presented as observable symptoms that require circuit-based explanation. Evidence from electrical/electronic education shows that problem-based intervention can support practical task performance (Orji, 2025), while circuit instruction using interactive problem-based methods has been used successfully with diverse mechatronics cohorts (Hassan et al., 2025). The present class-level shift suggests that similar problem framing is feasible in Light Vehicle Engineering.

Second, teachers should monitor individual trajectories rather than relying only on class means. A simple paired plot can reveal whether an instructional sequence reaches the whole class or mainly a subset. This is particularly valuable in light of evidence that self-regulation, motivation, instructor support, and involvement can shape vocational learning processes (Nordin et al., 2020; Rafiq et al., 2023; Wen & Sumettikoon, 2024). In the present study, universal gains are encouraging, but the persistent spread in post-test scores indicates a continuing need for targeted support.

Third, assessment should match the reasoning demanded by PBL. If students are expected to diagnose faults and justify decisions, outcome measures should include more than factual recall. Practical electrical assessment in Orji (2025), blended theoretical-practical assessment in Giatman and Mukhaiyar (2025), and broader cognitive-psychomotor-affective perspectives identified by Setyawan et al. (2025) illustrate possible directions. For automotive lighting, a multimethod assessment could combine conceptual questions, wiring-diagram interpretation, diagnostic scenarios, and hands-on fault tracing.

Fourth, technology can support but should not substitute for the problem-solving structure. Wang et al. (2023) used finite-element visualization to enrich PBL, Hidayat et al. (2025) integrated mobile augmented reality, and Wagino et al. (2025) combined PBL with an online ecosystem in automotive engineering. Related project-based research also suggests that digital or blended formats can strengthen technical learning when aligned with clear tasks (Giatman & Mukhaiyar, 2025; Leksono Edy et al., 2020). For novice automotive learners, technology should therefore be selected because it makes circuit behavior, fault evidence, or diagnostic consequences more visible, not merely because it is novel.

3.2.10 Directions for a stronger follow-up study

The current findings justify a more rigorous next-stage study. At minimum, a follow-up should include a comparison group receiving another instructional approach under comparable time, curriculum, teacher, and assessment conditions. Baseline equivalence should be examined, and post-test performance should be analyzed using an appropriate baseline-adjusted model. The supplied literature provides several methodological precedents: Orji (2025) used a quasi-experimental intervention-control design with MANCOVA, Giatman and Mukhaiyar (2025) used ANCOVA in a nonequivalent control-group study, and Isa and Azid (2021) compared treatment and control groups in TVET.

A larger multisite sample would also allow moderator analysis. Baseline achievement, prior electrical experience, attendance, motivation, self-regulation, and learning involvement are plausible candidates because related studies have highlighted the importance of diverse academic backgrounds, self-regulation, motivation, and involvement (Hassan et al., 2025; Nordin et al., 2020; Rafiq et al., 2023; Wen & Sumettikoon, 2024). Item-level assessment could determine which competencies respond most strongly, while delayed testing could assess retention. A longitudinal electronics study using flipped teaching also reported sustained learning advantages, illustrating the value of extending assessment beyond an immediate post-test (Lo et al., 2021).

Finally, future work should document implementation fidelity and examine mechanism. PBL outcomes may depend on problem authenticity, facilitation, collaboration, time on task, scaffolding, and access to representations or equipment. Career-focused project-based research suggests that authentic occupational scenarios can strengthen motivation and vocational skill development (Zhang & Yeoh, 2026), while scaffolding-PBL research shows that structured support can enable higher-order vocational cognition (Sukatiman & Akhyar, 2020). For automotive education, the productive question is therefore not merely whether PBL 'works,' but which problem designs and supports produce durable diagnostic learning for which students.

3.2.11 Research contribution and revised knowledge claim

The strongest contribution of this study is not a claim of first use of Problem-Based Learning in vocational education. The supplied literature already documents problem-based approaches across welding, air conditioning, geomatics, electrical/electronic technology, mechatronic circuits, and automotive e-learning (Azman & Adri, 2025; Hassan et al., 2025; Hidayat et al., 2025; Orji, 2025; Sukatiman & Akhyar, 2020; Wagino et al., 2025). The more defensible contribution is analytical: within the supplied evidence base, direct study of automotive lighting and signaling systems with complete individual paired trajectories is absent, and the present dataset shows a large upward shift that is positive for every observed learner despite wide baseline variation.

The resulting knowledge claim can be stated precisely. In this Grade XI Light Vehicle Engineering cohort, learning outcomes increased substantially following PBL, and improvement was distributed across the entire class rather than being generated by a limited subset of students. Baseline achievement continued to predict relative post-test position, so the instructional sequence was associated with broad progress without convergence. This combined pattern of universal positive gain and persistent heterogeneity extends the interpretation beyond a binary statement that 'PBL worked.'

That claim is scientifically bounded and educationally useful. It identifies a promising pattern, aligns it with a growing vocational literature on problem-centered and authentic learning, and simultaneously recognizes that stronger causal and measurement evidence is required. The next step is a controlled, well-documented evaluation that links cognitive gain to practical diagnostic performance and tests whether the same class-wide consistency can be reproduced across instructors and schools.

CONCLUSION

Problem-Based Learning in the topic of automotive lighting and signaling systems was followed by a substantial improvement in measured learning outcomes among 23 Grade XI Light Vehicle Engineering students. Mean scores increased from 36.09 before instruction to 62.83 afterward, yielding an average gain of 26.74 points. The paired difference was statistically significant, with a 95% confidence interval of 23.64-29.84 points, and the result was confirmed by a nonparametric Wilcoxon analysis. The standardized within-student change was very large.

The most important finding was the consistency of improvement. Every student recorded a higher post-test score than pre-test score, with gains between 15 and 35 points. This pattern indicates that the class-average improvement reflected broad individual progress rather than gains concentrated among a small number of students. At the same time, the strong association between pre-test and post-test scores and the continued spread of post-test performance show that PBL did not eliminate initial achievement differences.

The evidence therefore supports a carefully bounded conclusion: PBL was associated with large and universally positive within-student learning gains in this vocational automotive class, but the one-group design does not permit definitive attribution of the entire change to PBL alone. Future research should use a controlled design, document implementation fidelity, report instrument validity and reliability, and incorporate practical diagnostic performance and retention outcomes. Within the available evidence, the study demonstrates the value of examining individual learning trajectories alongside average scores and provides a defensible foundation for further evaluation of problem-centered instruction in automotive electrical education.

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