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Beyond scores: Self-efficacy and self-monitoring as mechanisms of project-based learning effects in an analog electronics course

Ilmiyati Rahmy Jasril
Universitas Negeri Padang, INDONESIA

Muhammad Anwar
Universitas Negeri Padang, INDONESIA

Muhammad Giatman
Universitas Negeri Padang, INDONESIA

Andhika Herayono
Universitas Negeri Padang, INDONESIA

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Abstract

Background: Project-Based Learning (PjBL) has been widely adopted in engineering education to improve students' achievement and engagement; however, most studies remain outcome-oriented and provide limited insight into the psychological mechanisms underlying its effectiveness. In technically demanding courses such as Analog Electronics, understanding how instructional strategies influence internal learning processes is essential for promoting meaningful learning.
Aim: This study aims to examine the effect of PjBL on students' learning achievement and to investigate whether self-efficacy and self-monitoring function as mediating variables linking PjBL to academic performance.
Method: A quantitative quasi-experimental design with a pretest–posttest non-equivalent control group was employed, involving 50 undergraduate engineering students (25 in the PjBL group and 25 in the control group). Data were collected using a learning achievement test and validated questionnaires measuring self-efficacy and self-monitoring. Data analysis was conducted using ANCOVA to assess treatment effects and mediation analysis with bootstrapping (5,000 resamples) to examine indirect effects.
Results: The results indicated that PjBL significantly improved students' posttest scores after controlling for prior knowledge. PjBL also significantly increased both self-efficacy and self-monitoring. However, mediation analysis revealed that only self-efficacy had a significant indirect effect on learning achievement, while self-monitoring did not show a unique mediating effect, likely due to its strong correlation with self-efficacy. The direct effect of PjBL on achievement remained significant, indicating partial mediation.
Conclusion: The findings suggest that PjBL enhances learning achievement both directly and indirectly through strengthening students' self-efficacy. This highlights the importance of incorporating motivational support within project-based environments to foster effective and sustainable learning in engineering education.

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INTRODUCTION

Improving learning outcomes in higher education is no longer confined to increasing students' test scores but extends to fostering deeper conceptual understanding, adaptive expertise, and self-regulated learning competencies. In engineering education, these expectations are particularly demanding because students must integrate theoretical knowledge with practical applications in complex problem-solving contexts (Hadgraft & Kolmos, 2020; Perrenet et al., 2000; Sigahi & Sznelwar, 2022). Courses such as Analog Electronics require learners to simultaneously interpret abstract representations, perform analytical reasoning, and make design decisions under constraints. However, traditional lecture-based approaches often emphasize procedural knowledge and content transmission, which may limit opportunities for meaningful engagement and higher-

* **Corresponding author:**
Ilmiyati Rahmy Jasril, Universitas Negeri Padang, Indonesia
ilmiyatirahmyjasril@ft.unp.ac.id

order thinking (Cherukuri, 2025). As a result, students frequently experience difficulties in connecting theory with practice, leading to fragmented understanding and reduced learning effectiveness. These challenges highlight the need for instructional approaches that actively engage learners in authentic tasks and promote deeper cognitive processing. Project-Based Learning (PjBL) has emerged as a promising alternative that aligns with these pedagogical demands. By situating learning within real-world problem contexts, PjBL encourages students to construct knowledge through active exploration and collaboration. Therefore, examining how such approaches influence learning processes has become increasingly important in contemporary engineering education.

Despite the growing adoption of PjBL, empirical observations indicate that many students still struggle to achieve optimal learning outcomes in technically demanding courses. In Analog Electronics, for instance, students often face difficulties in applying theoretical models to practical circuit design, interpreting signal behavior, and troubleshooting system errors. These challenges are compounded by the cognitive complexity of the subject, which requires sustained attention, iterative reasoning, and integration of multiple knowledge domains (Li, 2025; Nussbaum, 2021; Yan et al., 2024). Moreover, students frequently demonstrate low persistence when encountering complex tasks, suggesting limitations in their motivational and self-regulatory capacities. Observational studies have also shown that learners tend to rely on surface-level strategies rather than engaging in reflective and strategic learning processes (Granström et al., 2023; Han & Ellis, 2023). This phenomenon indicates that instructional innovation alone may not be sufficient unless it is accompanied by mechanisms that support students' internal learning processes. Consequently, understanding how students regulate their learning within project-based environments becomes a critical concern. Without such understanding, improvements in instructional design may not fully translate into meaningful learning gains. These empirical issues underline the importance of investigating both instructional and psychological dimensions of learning.

The urgency of this issue is further amplified by the increasing demand for graduates who possess not only technical competence but also the ability to learn independently and adapt to rapidly evolving technological environments. Engineering education is expected to produce learners who can engage in lifelong learning, problem-solving, and innovation (Hadgraft & Kolmos, 2020; Madhavi et al., 2024; Nafie, 2024). However, achieving these outcomes requires more than exposure to authentic tasks; it necessitates the development of self-regulated learning (SRL) competencies that enable students to manage their cognitive, motivational, and behavioral processes effectively. SRL theory emphasizes that learners actively construct knowledge by setting goals, monitoring progress, and adjusting strategies in response to task demands (Alam & Mohanty, 2024; Hadwin et al., 2025; Wu, 2024). Within this framework, motivational beliefs and metacognitive regulation play central roles in determining learning success. In project-based contexts, where tasks are open-ended and require sustained engagement, these regulatory processes become even more critical. Therefore, exploring how PjBL interacts with SRL components is essential for understanding its effectiveness. Such insights can inform the design of instructional environments that not only enhance performance but also support long-term learning development. This makes the investigation of underlying learning mechanisms both timely and necessary.

Among the key components of SRL, self-efficacy and self-monitoring have been identified as crucial determinants of academic performance. Self-efficacy refers to learners' beliefs in their ability to successfully perform specific tasks, which influences their motivation, persistence, and resilience when facing challenges (Abdolrezapour et al., 2023; Li, 2022; Waddington, 2023). In engineering education, students with higher self-efficacy are more likely to engage deeply in problem-solving activities and persist in overcoming technical difficulties. On the other hand, self-monitoring involves the continuous evaluation of one's understanding and strategy effectiveness, allowing learners to identify errors and regulate their learning processes (Al Harrasi, 2024; Zhu & Doo, 2022). In project-based environments, self-monitoring enables students to track their progress, evaluate design outcomes, and refine their approaches iteratively. Although both constructs are theoretically interconnected, they represent distinct aspects of self-regulated learning that may contribute differently to academic achievement. Understanding their roles within instructional contexts is therefore essential. Particularly in Analog Electronics, where tasks require iterative refinement and reflective thinking, these processes are expected to play a significant role. Consequently, examining how these constructs function within PjBL environments provides a strong rationale for this study.

A substantial body of research has demonstrated the effectiveness of Project-Based Learning in enhancing students' academic performance, engagement, and higher-order thinking skills. Studies have shown that PjBL promotes active learning, collaboration, and the application of knowledge in authentic contexts (Omelianenko & Artyukhova, 2024; Tan & Huet, 2021; Williamson, 2023). In engineering education, PjBL has been associated with improved conceptual understanding, problem-solving ability, and professional skill development (Husin et al., 2025; Karan & Brown, 2022). Furthermore, research indicates that project-based environments can foster self-regulated learning by encouraging students to take responsibility for their learning processes (Wu, 2024). Self-efficacy, in particular, has been widely recognized as a key predictor of academic success, with numerous studies reporting its positive relationship with learning outcomes (Basith et al., 2020; Honicke et al., 2020; Moussa, 2023). Similarly, self-monitoring has been linked to improved learning strategies and academic achievement, especially in complex learning environments (Zhu & Doo, 2022). Despite these findings, most studies have examined these variables independently rather than within an integrated framework. This fragmented approach limits the understanding of how multiple SRL components interact within instructional contexts. Therefore, a more comprehensive analysis is needed to capture the complexity of learning processes in project-based environments.

However, several important limitations remain in the existing literature. First, many studies on PjBL focus primarily on outcome-based indicators such as test scores, providing limited insight into the psychological mechanisms that underlie observed learning gains (Goyal et al., 2022; M. Li & Rohayati, 2024). Second, research on self-regulated learning in engineering education often treats motivational and metacognitive components as separate predictors, without examining their simultaneous and interactive roles (Li et al., 2020; Zheng et al., 2020). Third, empirical investigations that employ mediation analysis to explore the indirect effects of instructional strategies on learning outcomes are still relatively scarce, particularly in discipline-specific contexts such as Analog Electronics. Moreover, the potential conceptual overlap between constructs such as self-efficacy and self-monitoring has not been sufficiently addressed, which may lead to ambiguous findings (Alemayehu & Chen, 2023). These limitations indicate that current research has not fully captured the complexity of learning processes in project-based environments. As a result, the extent to which PjBL influences learning outcomes directly or indirectly through self-regulatory mechanisms remains unclear. Addressing this gap requires a structural approach that integrates multiple variables within a unified analytical framework. This highlights the need for further investigation into the mechanisms underlying PjBL effectiveness.

In response to these gaps, the present study aims to investigate the structural relationships among Project-Based Learning, self-efficacy, self-monitoring, and learning achievement in an undergraduate Analog Electronics course. Specifically, this research examines whether self-efficacy and self-monitoring function as mediating variables linking PjBL to students' academic performance while controlling for prior knowledge. By integrating motivational and metacognitive constructs within a single analytical framework, this study seeks to provide a more comprehensive understanding of how instructional strategies influence learning outcomes. Theoretically, the study contributes to the advancement of self-regulated learning research by examining the interplay between different SRL components in a project-based context. Practically, the findings offer insights for educators in designing learning environments that not only enhance achievement but also foster students' confidence and reflective learning practices. In addition, the study addresses the need for discipline-specific research in engineering education, particularly in courses that require complex cognitive processing. By moving beyond outcome-based evaluation, this research emphasizes the importance of understanding the mechanisms that drive effective learning. Ultimately, the study aims to inform the development of pedagogical models that support sustainable and meaningful learning in higher education.

LITERATURE REVIEW

Project-Based Learning in Engineering Education

Project-Based Learning (PjBL) has been widely recognized as an effective learner-centered instructional approach in engineering and vocational education (Ibrahim, 2025). Unlike traditional lecture-based instruction, PjBL emphasizes active knowledge construction through authentic tasks, collaborative inquiry, and real-world problem solving (Williamson, 2023). In engineering disciplines, including Analog Electronics, project-based activities provide opportunities for students to apply theoretical concepts in designing circuits, analyzing signal behavior, and troubleshooting system performance (Yang, 2021; Yu et al., 2026). Such experiential learning environments are believed to enhance conceptual understanding, practical competence, and student engagement. Previous studies have shown that PjBL can improve academic performance, motivation, and higher-order thinking skills by promoting meaningful learning experiences (Kusumawati & Fauzan, 2025). Through iterative design processes and reflective practice, students develop problem-solving strategies that extend beyond procedural knowledge. Moreover, project-based environments encourage learners to take responsibility for their learning progress, which aligns with contemporary educational goals emphasizing autonomy and lifelong learning competencies. Despite these advantages, the extent to which PjBL directly influences learning achievement or operates through underlying psychological mechanisms remains an important area of investigation.

Self-Regulated Learning: Self-Efficacy and Self-Monitoring

Self-regulated learning (SRL) theory provides a useful framework for understanding how students manage their learning processes in complex instructional environments (Alvi & Gillies, 2020; Gambo & Shakir, 2023). SRL refers to learners' active involvement in setting goals, selecting strategies, monitoring progress, and evaluating outcomes. Within this framework, motivational and metacognitive components play complementary roles in shaping academic behavior. One key motivational construct is self-efficacy, defined as students' beliefs in their ability to successfully perform learning tasks. High self-efficacy has been associated with increased persistence, effort, and resilience when facing challenging academic problems. In Analog Electronics learning contexts, students with stronger self-efficacy are more likely to engage deeply in circuit design tasks, experiment with alternative solutions, and persist in debugging technical errors.

Another important SRL component is self-monitoring, which involves learners' ongoing evaluation of their understanding and strategy effectiveness. Self-monitoring enables students to detect misconceptions, adjust their approaches, and regulate their learning pace (Zhu & Bonk, 2020; Zhu & Doo, 2022). In project-based settings, where tasks are often extended and complex, the ability to continuously reflect on learning progress becomes critical for achieving successful outcomes. Although both constructs are theoretically relevant, empirical research examining their simultaneous roles in mediating instructional effects remains limited.

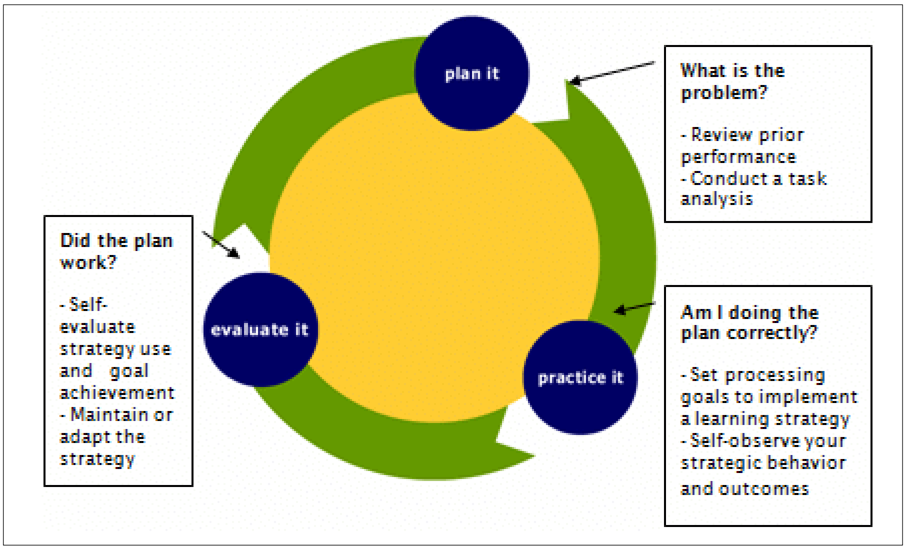

Figure 1. Zimmermans model of Self-Regulated Learning (Zimmerman, 2021)

Learning Achievement and Mediation Mechanisms in Project-Based Contexts

Learning achievement in engineering education is influenced by multiple interacting factors, including instructional design, prior knowledge, motivation, and metacognitive regulation. While numerous studies have reported positive relationships between PjBL and academic performance, fewer investigations have explored the structural pathways that explain these relationships. In particular, it is still unclear whether improvements in learning achievement occur primarily through enhanced self-regulatory processes or through direct instructional effects. From a theoretical perspective, project-based learning environments may enhance learning achievement indirectly by strengthening students' self-efficacy and self-monitoring abilities (Wu, 2024). Increased confidence in handling complex tasks can motivate learners to invest greater effort, while improved monitoring skills allow them to regulate learning strategies more effectively. At the same time, PjBL may also exert a direct influence on achievement by providing structured opportunities for knowledge application and skill development. Understanding the balance between these direct and indirect pathways is essential for designing instructional models that optimize both performance outcomes and long-term learning competencies.

Theoretical Framework and Hypothesis Development

Project-Based Learning (PjBL) provides structured learning experiences that encourage students to engage in authentic problem-solving activities requiring sustained effort, strategic thinking, and reflective learning. In technically demanding courses such as Analog Electronics, students are expected not only to understand theoretical concepts but also to apply them in designing circuits, analyzing signals, and troubleshooting real-world problems. From the perspective of self-regulated learning (SRL), such instructional environments are likely to influence students' motivational beliefs and metacognitive regulation, which in turn affect their learning achievement.
Self-efficacy represents students' confidence in their ability to successfully perform academic tasks. Project-based experiences that involve mastery-oriented activities may strengthen students' confidence and persistence when facing complex learning challenges. Meanwhile, self-monitoring refers to students' ability to continuously evaluate their learning progress and adjust strategies accordingly. In project-based settings, these regulatory behaviors are essential for managing extended tasks and achieving successful outcomes.

Learning achievement in engineering education is influenced by both instructional strategies and students' internal learning mechanisms. Project-Based Learning may exert a direct influence on achievement by providing meaningful opportunities for knowledge application. At the same time, indirect effects may occur through improvements in self-efficacy and self-monitoring. Therefore, this study proposes a structural framework examining both direct and mediated relationships among Project-Based Learning, self-efficacy, self-monitoring, and learning achievement.

METHOD

Research Design

This study employed a quantitative quasi-experimental design using a pretest–posttest non-equivalent control group structure. This design was selected to examine the causal effect of Project-Based Learning (PjBL) on students' learning achievement while simultaneously investigating the mediating roles of self-efficacy and self-monitoring. Random assignment was not feasible because the participants were organized into intact classes; therefore, a quasi-experimental approach was considered the most appropriate to preserve ecological validity within a real classroom context. The design allowed for comparison between a treatment group receiving PjBL and a control group experiencing conventional lecture-based instruction, while controlling for prior knowledge using pretest scores. In addition, mediation analysis was incorporated to explore the indirect effects of instructional strategy through psychological mechanisms. This combination of group comparison and mediation modeling provides both explanatory and inferential insights into learning processes. The approach aligns with contemporary educational research emphasizing mechanism-based explanations rather than solely outcome-based evaluation. Therefore, the chosen design supports both internal validity and theoretical contribution.

Research Setting and Duration

The study was conducted at an undergraduate engineering education program in a public university during the odd semester of the 2025/2026 academic year, over a period of approximately 14 weeks. The research was situated in an Analog Electronics course, which includes topics such as amplifier design, signal analysis, biasing circuits, and troubleshooting electronic systems. This course was selected because of its high level of cognitive demand, requiring students to integrate conceptual understanding with practical application. The instructional intervention was implemented throughout the semester, ensuring sufficient exposure to the learning model. The treatment group participated in structured project-based activities, while the control group received lecture-based instruction with guided exercises. Both groups followed the same syllabus, assessment schedule, and instructional duration to maintain consistency. Data were collected at two main points: before the intervention (pretest) and after the intervention (posttest). This setting provided a controlled yet authentic environment for evaluating instructional effectiveness. Consequently, the research context was appropriate for examining both learning outcomes and underlying mechanisms.

Participants and Sampling

The population of this study consisted of all undergraduate students enrolled in the Analog Electronics course during the specified semester. A total of 50 students participated, divided into two intact classes: 25 students in the PjBL group and 25 students in the control group. A purposive sampling technique was used, as the classes were pre-assigned by the institution and could not be randomly reorganized. Inclusion criteria required students to be officially registered in the course, actively engaged in the learning process, and completing both pretest and posttest assessments. Students who did not complete all required instruments were excluded from the analysis to ensure data integrity. The sample size was considered adequate for mediation analysis using bootstrapping procedures, although it is not intended for large-scale structural equation modeling. Descriptive statistics indicated that both groups were comparable in terms of age, prior academic performance, and baseline knowledge. This comparability supports the validity of group comparisons. The participants represent a typical cohort of engineering students, enhancing the ecological validity of the study. Therefore, the sample was appropriate for addressing the research objectives.

Research Instruments

Data were collected using three primary instruments: a learning achievement test, a self-efficacy questionnaire, and a self-monitoring questionnaire. The learning achievement test was developed based on course learning outcomes and consisted of analytical and problem-solving items measuring students' ability to apply electronic concepts. The self-efficacy questionnaire assessed students' confidence in performing tasks related to circuit design, analysis, and troubleshooting. The self-monitoring questionnaire measured students' ability to evaluate their learning progress, detect errors, and adjust strategies. Both questionnaires employed a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The instruments were constructed based on established theoretical frameworks, particularly Bandura's self-efficacy theory and Zimmerman's self-regulated learning model. Each construct was operationalized through multiple indicators to capture its multidimensional nature. The questionnaires were administered after the instructional intervention to reflect students' learning experiences. These instruments enabled the measurement of both cognitive outcomes and internal learning processes. Therefore, they were suitable for the study's objectives.

Validity and Reliability of Instruments

The validity and reliability of the instruments were established through several procedures. Content validity was ensured through expert judgment involving three specialists in engineering education and educational psychology. These experts evaluated the relevance, clarity, and alignment of the items with the intended constructs. Construct validity was examined using exploratory factor analysis, with a minimum factor loading threshold of 0.50. Items that did not meet this criterion were removed to improve measurement accuracy. Reliability was assessed using Cronbach's alpha, with coefficients exceeding 0.90 for both self-efficacy and self-monitoring, indicating high internal consistency. The learning achievement test was also analyzed for item difficulty and discrimination indices to ensure quality. A pilot study was conducted with a group of students outside the main sample to refine the instruments. These procedures ensured that the instruments were both valid and reliable. Consequently, the data collected were considered robust for further statistical analysis.

Data Collection Procedure

The data collection process was carried out in a systematic and structured manner. In the preparation phase, institutional approval was obtained, and participants were informed about the purpose and procedures of the study. In the implementation phase, the pretest was administered at the beginning of the semester to assess prior knowledge. The treatment group then engaged in project-based learning activities, including planning, designing, testing, and reflecting on electronic systems. Meanwhile, the control group received lecture-based instruction with guided exercises. At the end of the semester, the posttest and questionnaires were administered to both groups under standardized conditions. In the documentation phase, all data were recorded, coded, and organized for analysis. Missing or incomplete data were handled using listwise deletion. The entire process was monitored to ensure consistency and minimize bias. This structured procedure ensured the reliability of data collection. Therefore, the study maintained procedural rigor throughout its implementation. To provide a clear overview of the research process, the following flowchart illustrates the sequence of methodological steps:

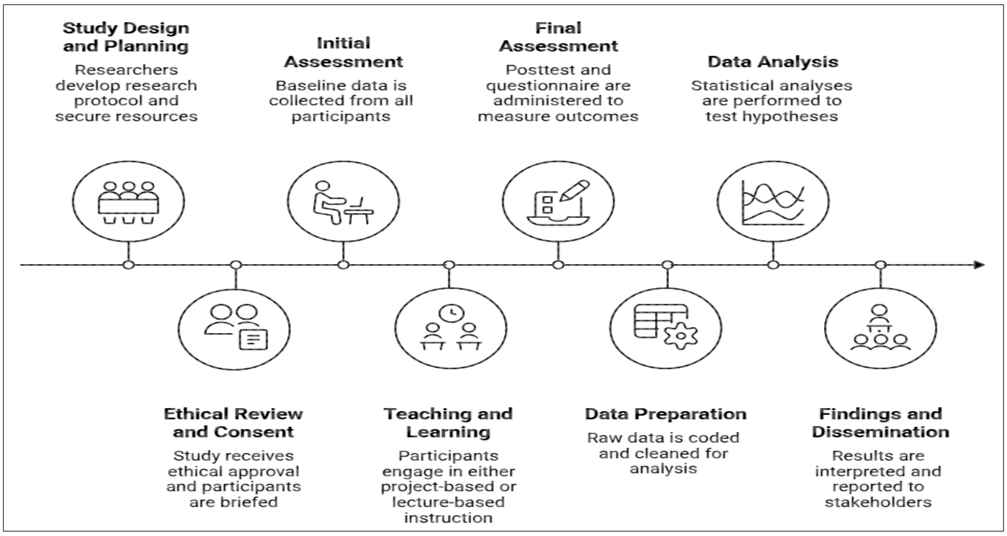

Figure 2. Research Procedure Flowchart

Data Analysis Techniques

Data analysis was conducted using IBM SPSS version 29 and the PROCESS macro (Model 4). Descriptive statistics were used to summarize participant characteristics and variable distributions. Analysis of Covariance (ANCOVA) was employed to test the effect of PjBL on posttest scores while controlling for pretest scores. Effect sizes were reported using partial eta squared (η^2) and Hedges' g. Mediation analysis was performed using bootstrapping with 5,000 resamples to estimate indirect effects and their 95% confidence intervals. An indirect effect was considered significant if the confidence interval did not include zero. Assumptions such as normality, homogeneity of variance, and multicollinearity were tested prior to analysis. The high correlation between self-efficacy and self-monitoring was carefully considered in interpreting the results. This analytical approach allows for robust estimation of both direct and indirect effects. Therefore, the selected techniques are appropriate for the research design.

RESULTS AND DISCUSSION

Results

Descriptive Statistics and Reliability

Pretest scores were broadly comparable between groups. Posttest and gain scores favored the Project Based Learning (PjBL) group. Both psychological scales demonstrated high internal consistency (self efficacy α = .933; self monitoring α = .904).

Table 2. Descriptive Statistics by Group (N = 50)

Variable	Control Mean	Control SD	PjBL Mean	PjBL SD	Hedges' g	Notes
Pretest	67.56	8.19	69.32	9.24	—	Baseline
Posttest	70.20	6.87	75.00	9.64	0.59	Outcome
Gain (Post–Pre)	2.64	3.05	5.68	3.16	0.97	Primary effect size
Self-efficacy	3.83	0.98	4.67	0.39	1.11	Scale α=.933
Self-monitoring	3.98	0.94	4.84	0.26	1.23	Scale α=.904

ANCOVA Treatment Effect and Mediation Analysis

ANCOVA (posttest controlling for pretest) indicated a significant PjBL effect: b = 3.22 points, $p < .001$, with partial $\eta^2 \approx .233$. Holding baseline achievement constant, students in the PjBL condition scored about 3.2 points higher on the posttest. ANCOVA results (posttest controlling for pretest) indicated a significant effect of Project-Based Learning (b = 3.22 points, $p < .001$), with a partial η^2 of approximately .233. After controlling for baseline achievement, students in the PjBL condition scored about 3.2 points higher on the posttest compared to those in the conventional instruction group.

Project-Based Learning significantly increased both self-efficacy (a = 0.82, $p < .001$) and self-monitoring (a = 0.85, $p < .001$). The two mediators were strongly correlated (r = .874). In the parallel mediation model, the bootstrap indirect effect via self-efficacy was supported (mean ≈ 1.59; 95% CI [0.29, 3.71]), whereas the unique indirect effect via self-monitoring was not supported (mean ≈ −1.21; 95% CI [−2.97, 0.58]). The remaining direct effect of PjBL remained significant (c' mean ≈ 2.85; 95% CI [0.79, 4.82]), suggesting partial and/or overlapping mediation.

Table 3. Mediation Model Summary

Effect	Estimate	Notes	Bootstrap 95% CI
a (PjBL → Self-efficacy)	0.82	Pretest as covariate	—
a (PjBL → Self-monitoring)	0.85	Pretest as covariate	—
Indirect via Self-efficacy	1.59	Bootstrap mean	[0.29, 3.71]
Indirect via Self-monitoring	−1.21	Bootstrap mean	[−2.97, 0.58]
Direct effect c'	2.85	Bootstrap mean	[0.79, 4.82]

Structural Model Results

To examine the simultaneous relationships among Project-Based Learning (PjBL), self-efficacy, self-monitoring, and learning achievement, a structural model was estimated. The model incorporated pretest scores as a control variable to account for baseline differences in prior knowledge. The structural model results are presented in Figure 3. The analysis indicated that Project-Based Learning significantly predicted both self-efficacy ($\beta = 0.82$, $p < .001$) and self-monitoring ($\beta = 0.85$, $p < .001$), suggesting that students exposed to project-based instructional activities demonstrated stronger motivational beliefs and metacognitive regulation. These findings support the assumption that learner-centered instructional environments promote self-regulated learning processes. In terms of outcome prediction, self-efficacy showed a significant positive effect on learning achievement ($\beta = 0.28$, $p < .05$), indicating that students with higher confidence in their academic capabilities tended to achieve better posttest performance. In contrast, self-monitoring did not exhibit a statistically significant unique effect on learning achievement ($\beta = 0.07$, ns), despite its strong correlation with self-efficacy. This pattern suggests potential conceptual overlap between motivational and metacognitive regulatory processes within the project-based learning context.

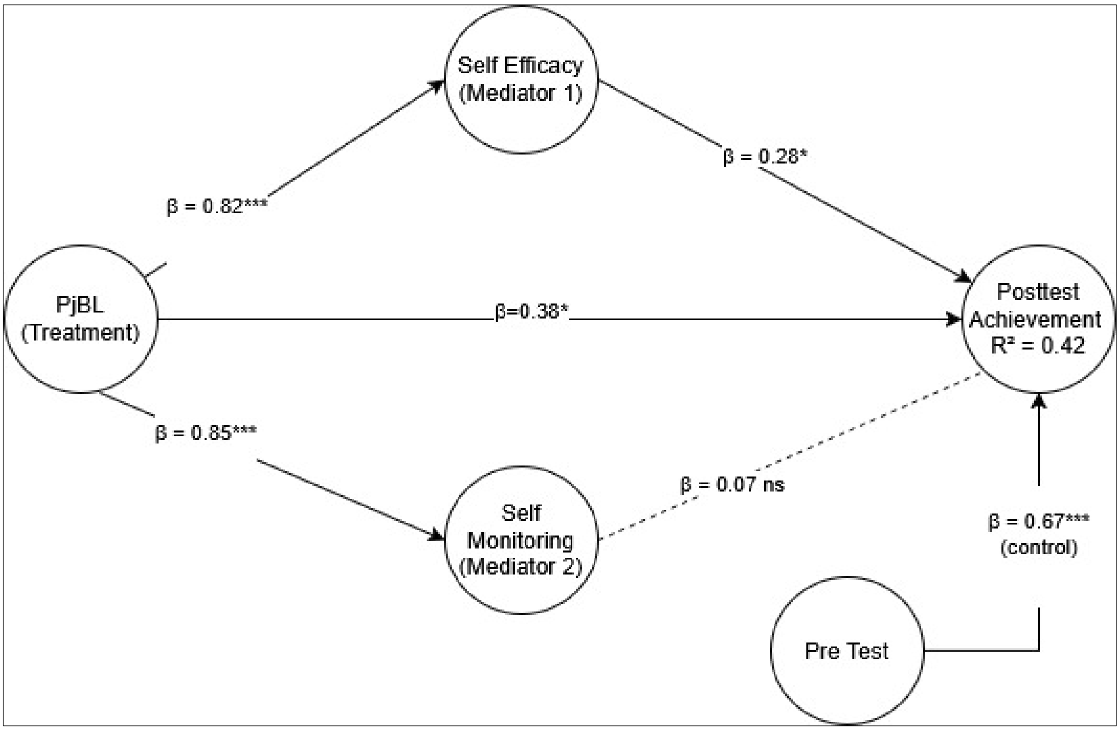

Figure 3. Structural Model Result

The direct effect of Project-Based Learning on learning achievement remained significant (β = 0.38, $p < .05$), even after accounting for the mediating variables. This result indicates that Project-Based Learning contributes to academic performance not only through psychological mechanisms but also through direct instructional benefits, such as opportunities for applied practice and collaborative problem-solving. Furthermore, pretest scores demonstrated a substantial positive effect on posttest achievement (β = 0.67, $p < .001$), highlighting the importance of prior knowledge in predicting learning outcomes. The structural model explained a moderate proportion of variance in learning achievement ($R^2 = 0.42$), indicating that the proposed model provides meaningful explanatory power in understanding students' academic performance in the Analog Electronics course. Overall, the structural findings support a partial mediation pattern, in which self-efficacy functions as a key mechanism linking Project-Based Learning to learning achievement, while self-monitoring shows a weaker and non-unique contribution.

Discussion

The first major finding of this study indicates that Project-Based Learning (PjBL) significantly improves students' learning achievement in Analog Electronics, even after controlling for prior knowledge. This result suggests that the effectiveness of PjBL is not merely a reflection of initial academic differences but represents a genuine instructional impact. Conceptually, this aligns with constructivist learning theory, which posits that knowledge is actively constructed through meaningful engagement with tasks rather than passively received (Hadgraft & Kolmos, 2020; Yan et al., 2024). In complex domains such as Analog Electronics, where learners must integrate abstract theory with practical design, PjBL provides cognitive scaffolding through authentic problem-solving experiences. Empirical studies have consistently reported similar findings, demonstrating that PjBL enhances conceptual understanding and performance in engineering contexts (Husin et al., 2025; Omelianenko & Artyukhova, 2024; Yu et al., 2026). However, some studies have found more modest effects, particularly in contexts where projects are poorly structured or insufficiently guided (Goyal et al., 2022). This discrepancy suggests that the effectiveness of PjBL is contingent upon instructional design quality, including task clarity and feedback mechanisms. Therefore, the present finding reinforces the argument that well-implemented PjBL can serve as a powerful instructional approach for cognitively demanding disciplines. It also implies that active learning environments are essential for bridging the gap between theoretical knowledge and practical application.

A second important finding reveals that PjBL significantly enhances students' self-efficacy, indicating that project-based environments foster stronger beliefs in one's ability to perform complex academic tasks. From a theoretical perspective, this finding is consistent with Bandura's social cognitive theory, which emphasizes mastery experiences as the most influential source of self-efficacy development (Waddington, 2023; Abdolrezapour et al., 2023). In PjBL settings, students repeatedly engage in iterative design, testing, and problem-solving processes, which provide opportunities for successful task completion and reinforce confidence. This mechanism explains why students exposed to PjBL demonstrate higher levels of persistence and engagement when facing challenging tasks. Previous research supports this relationship, showing that learner-centered and experiential approaches significantly increase self-efficacy across STEM disciplines (Moussa, 2023; Alam & Mohanty, 2024; Wu, 2024). Nevertheless, some studies have reported weaker effects when students lack sufficient prior knowledge or instructional support (Han & Ellis, 2023). This suggests that the development of self-efficacy is not automatic but depends on the alignment between task difficulty and learner readiness. Consequently, the present study extends existing literature by confirming that PjBL can effectively enhance motivational beliefs when implemented within a supportive instructional framework. This highlights the importance of designing learning environments that provide both challenge and achievable success experiences.

The third finding demonstrates that PjBL significantly increases students' self-monitoring abilities, reflecting improvements in metacognitive regulation within project-based environments. This result supports the theoretical framework of self-regulated learning (SRL), which posits that learners actively monitor and adjust their cognitive processes during complex tasks (Hadwin et al., 2025; Gambo & Shakir, 2023). In the context of Analog Electronics, self-monitoring is critical for identifying errors in circuit design, evaluating signal behavior, and refining solutions iteratively. The project-based structure inherently requires students to engage in continuous reflection, thereby promoting metacognitive awareness. Empirical evidence also suggests that PjBL fosters self-monitoring by encouraging learners to evaluate progress and adapt strategies (Zhu & Doo, 2022; Wu, 2024). However, some studies indicate that metacognitive gains may be limited when explicit reflective scaffolding is absent (Granström et al., 2023). This implies that while PjBL creates opportunities for self-monitoring, its effectiveness depends on instructional guidance that supports reflection. Therefore, the current finding contributes to the literature by demonstrating that PjBL can enhance metacognitive processes in technically complex learning environments. It also underscores the need to integrate structured reflection within project-based tasks to maximize learning benefits.

A particularly significant finding of this study is that self-efficacy functions as a significant mediator between PjBL and learning achievement. This indicates that the effect of PjBL on academic performance operates not only directly but also indirectly through motivational mechanisms. Theoretically, this finding reinforces the central role of self-efficacy within SRL frameworks, where motivational beliefs influence effort, persistence, and strategic engagement (Honicke et al., 2020; Basith et al., 2020). In this context, students who believe in their capabilities are more likely to invest cognitive resources and persist in solving complex problems, leading to improved achievement outcomes. Previous studies have reported similar mediation effects, highlighting self-efficacy as a key pathway linking instructional strategies to performance (Alemayehu & Chen, 2023; Moussa, 2023). However, some research has treated self-efficacy as an independent predictor rather than an intervening variable, limiting the understanding of its functional role. The present study extends the literature by explicitly modeling self-efficacy as a mediator, thereby providing a more nuanced explanation of how PjBL influences learning outcomes. This finding suggests that instructional effectiveness should be evaluated not only in terms of cognitive outcomes but also in terms of its impact on learners' beliefs. Consequently, strengthening self-efficacy emerges as a critical target for instructional design.

In contrast, the finding that self-monitoring does not function as a significant unique mediator presents an important theoretical and empirical challenge. Although self-monitoring increased under PjBL, its indirect effect on learning achievement was not statistically significant when analyzed alongside self-efficacy. One plausible explanation is the high correlation between the two constructs, which may indicate conceptual overlap and shared variance (Alemayehu & Chen, 2023). From a theoretical standpoint, this suggests that metacognitive regulation may be partially embedded within motivational processes, particularly in complex learning environments where confidence influences reflective behavior. Some studies have reported similar patterns, where self-monitoring effects become non-significant when motivational variables are included in the model (Zheng et al., 2020). However, other research has found independent contributions of metacognitive processes, especially in contexts with explicit strategy instruction (Zhu & Doo, 2022). This discrepancy highlights the importance of contextual factors in shaping the role of self-monitoring. The present finding challenges the assumption that all SRL components contribute equally to learning outcomes and suggests a hierarchical relationship between motivation and metacognition. Therefore, this study contributes to theory by indicating that self-efficacy may dominate as a primary mechanism in project-based learning contexts.

Another key finding is that the direct effect of PjBL on learning achievement remains significant even after accounting for mediating variables, indicating partial mediation. This suggests that PjBL influences learning outcomes through both psychological mechanisms and direct instructional benefits. From a pedagogical perspective, this direct effect can be attributed to opportunities for active learning, collaboration, and real-world problem-solving inherent in PjBL environments (Karan & Brown, 2022; Tan & Huet, 2021). These features enable students to apply knowledge in meaningful contexts, thereby enhancing understanding and retention. Previous studies have similarly reported direct effects of PjBL on academic performance, even when controlling for other variables (Husin et al., 2025; Williamson, 2023). However, the persistence of direct effects also suggests that not all underlying mechanisms have been captured in the current model. Factors such as engagement, cognitive load, and collaborative dynamics may also play important roles. This indicates that the relationship between instructional strategies and learning outcomes is multifaceted and cannot be fully explained by a limited set of variables. Consequently, the present study expands the understanding of PjBL effectiveness by demonstrating the coexistence of direct and indirect pathways. It also highlights the need for more comprehensive models in future research.

The strong influence of prior knowledge on posttest achievement represents another critical finding that warrants careful interpretation. The significant effect of pretest scores indicates that baseline knowledge remains a dominant predictor of learning outcomes, even within innovative instructional environments. This finding aligns with cognitive learning theory, which emphasizes the role of prior knowledge in facilitating new learning through schema activation (Yan et al., 2024). In Analog Electronics, where concepts build cumulatively, students with stronger initial understanding are better positioned to benefit from project-based activities. Previous research has consistently shown that prior knowledge moderates the effectiveness of instructional strategies (Han & Ellis, 2023; Nussbaum, 2021). However, some studies suggest that well-designed PjBL can reduce achievement gaps by providing differentiated learning opportunities (Wu, 2024). The present finding indicates that while PjBL is effective, it does not fully compensate for differences in initial competence. This highlights the importance of incorporating scaffolding strategies to support learners with lower prior knowledge. Therefore, the study contributes to the literature by reaffirming the central role of prior knowledge in shaping learning outcomes. It also suggests that instructional innovation should be complemented by targeted support mechanisms.

From a broader perspective, the findings of this study provide important contributions to the global literature on engineering education and self-regulated learning. By integrating motivational and metacognitive variables within a single mediation framework, this research addresses a significant gap in previous studies that have examined these constructs in isolation (Li & Rohayati, 2024; Ibrahim, 2025). The results suggest that the effectiveness of instructional strategies cannot be fully understood without considering the interplay between cognitive, motivational, and metacognitive processes. This integrated perspective advances theoretical understanding by highlighting the dynamic interactions among SRL components in authentic learning environments. Furthermore, the study provides empirical evidence from a discipline-specific context, which is often underrepresented in SRL research. This contributes to the generalizability of SRL theory across different academic domains. The findings also offer practical insights for educators, emphasizing the need to design learning environments that support both performance and internal learning processes. Therefore, the study not only confirms existing theories but also extends them by demonstrating their applicability in complex, real-world educational settings. It positions PjBL as a multidimensional instructional approach that operates through both observable and latent mechanisms.

Finally, a critical reflection on the findings suggests that contextual and methodological factors may have influenced the observed results. The relatively small sample size may limit the statistical power of mediation analysis, particularly for detecting subtle effects of self-monitoring. Additionally, the high correlation between mediators raises concerns about multicollinearity, which may obscure unique contributions of individual variables. The absence of longitudinal data also restricts the ability to capture dynamic changes in self-regulated learning processes over time. Alternative explanations, such as the role of collaborative interaction or cognitive load, were not directly examined in this study. These limitations indicate that the findings should be interpreted with caution and highlight areas for future research. Nevertheless, the study provides a robust foundation for further investigation into the mechanisms underlying instructional effectiveness. It demonstrates the importance of adopting a critical and integrative approach to understanding learning processes. Ultimately, this research contributes to the ongoing effort to develop pedagogical models that support meaningful and sustainable learning in higher education.

CONCLUSION

This study demonstrates that Project-Based Learning (PjBL) significantly enhances students' learning achievement in an undergraduate Analog Electronics course, even after controlling for prior knowledge, confirming its effectiveness as a learner-centered instructional approach in technically demanding contexts. More importantly, the findings reveal that this improvement is not merely a direct instructional effect but is partly explained by psychological mechanisms, particularly self-efficacy, which emerged as a significant mediator linking PjBL to academic performance. Students engaged in project-based environments developed stronger confidence in managing complex tasks, which in turn supported persistence, deeper engagement, and improved problem-solving outcomes. In contrast, although self-monitoring increased under PjBL, its unique mediating effect was not statistically significant when analyzed alongside self-efficacy, suggesting a substantial conceptual and functional overlap between motivational and metacognitive regulatory processes. These results contribute to the theoretical advancement of self-regulated learning by highlighting the intertwined nature of its components within authentic learning environments. Practically, the study underscores the importance of designing PjBL environments that explicitly foster students' confidence and reflective learning behaviors through structured feedback, iterative tasks, and meaningful challenges. Despite its contributions, the study is limited by its modest sample size and single-course context, indicating the need for further research across diverse settings and larger populations. Future studies are also encouraged to incorporate longitudinal designs and behavioral learning analytics to better capture the dynamic processes underlying learning in project-based environments. Overall, this research provides a comprehensive understanding of how instructional strategies and internal learning mechanisms interact to shape academic success in engineering education.

AUTHOR CONTRIBUTIONS STATEMENT

IRJ took the lead in conceptualizing and designing the study and served as the primary author responsible for writing the original draft and coordinating the research process. **MA** contributed to the development of the research methodology, supervised the data collection process, and provided critical revisions to improve the intellectual content of the manuscript. **MG** was responsible for data analysis, including statistical testing and interpretation of the results, and contributed to refining the analytical framework. **AH** supported data curation and instrument validation and assisted in reviewing and editing the manuscript to ensure clarity, coherence, and academic quality.

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