

PAPER

Planning, Cognitive Strategy, and Self-Checking in Project-Based Learning: Which Learning Strategies Best Predict HOTS Gains?

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ABSTRACT

Higher-order thinking skills (HOTS) are essential outcomes in engineering education, yet the mechanisms through which project-based learning (PjBL) enhances HOTS remain insufficiently understood. Drawing on self-regulated learning (SRL) theory, this study examines how PjBL and SRL jointly relate to HOTS development in an undergraduate analog electronics course. A quasi-experimental pretest–posttest control group design was employed involving 50 engineering students assigned to PjBL and conventional instruction groups. SRL was conceptualized as a latent construct reflected by planning, cognitive strategy use, and self-checking behaviors. Data were analyzed using structural equation modeling to test relationships among instructional condition, SRL, HOTS gain, and posttest HOTS while controlling for baseline ability. Results indicate that PjBL significantly enhances SRL engagement, and SRL contributes positively to HOTS gain. PjBL also shows a direct effect on HOTS gain, indicating partial mediation. Baseline HOTS strongly predicts posttest performance, confirming the stability of higher-order thinking ability. The findings highlight SRL as a key mechanism through which project-based learning promotes higher-order cognitive development in engineering education.

KEYWORDS

project-based learning (PjBL), self-regulated learning (SRL), higher-order thinking skills (HOTS), engineering education, HOTS gain, analog electronics, structural equation modeling

1 INTRODUCTION

The rapid evolution of engineering and technology fields requires graduates to possess not only conceptual knowledge but also higher-order thinking skills (HOTS), including analysis, evaluation, and problem-solving abilities. In engineering education, HOTS is essential because professional practice requires graduates to diagnose system behavior, evaluate design alternatives, solve complex design problems, and make adaptive

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decisions in authentic contexts [1] [2] [3]. Consequently, instructional approaches capable of enhancing HOTS have become a major focus of contemporary pedagogy. Project-based learning (PjBL) has been widely adopted as a learner-centered approach that situates learning within authentic projects and real-world problem contexts [4] [5]. Through iterative design, testing, and refinement, PjBL promotes deep cognitive processing and reflective thinking associated with HOTS development. Although prior studies report that PjBL improves conceptual understanding and problem-solving ability, the mechanisms through which it enhances HOTS remain insufficiently clarified, particularly regarding learners' regulatory strategies during project work [6].

Self-regulated learning (SRL) provides a theoretical explanation for how PjBL may influence HOTS [7] [8]. Successful project work requires students to plan tasks, apply cognitive strategies, and monitor progress, corresponding to the forethought, performance, and self-reflection phases of SRL [9] [10]. SRL has been consistently linked to academic achievement and complex learning outcomes, including knowledge integration and transfer in engineering contexts [11]. Nevertheless, empirical findings are mixed regarding whether individual SRL strategies uniquely predict learning outcomes when instructional conditions and prior ability are considered simultaneously [12]. Moreover, baseline ability often remains the strongest predictor of post-instruction performance in pre-post designs, reflecting cumulative knowledge structures and learning readiness. Thus, understanding HOTS development requires integrating instructional approach, regulatory processes, and prior knowledge within a unified model. Few studies in engineering education have examined the relationships among PjBL, SRL, learning gains, and baseline performance simultaneously using structural modeling [13].

Self-regulated learning is widely recognized as a critical determinant of deep learning and complex skill acquisition [14]. In engineering learning environments involving system analysis, troubleshooting, and design optimization, regulatory processes such as planning, cognitive strategy use, and self-checking are particularly critical [15] [16]. Planning structures project goals and resource allocation, cognitive strategies support conceptual integration and problem representation, and self-checking enables error detection and iterative refinement [17] [18]. Empirical evidence suggests that these strategies operate as an integrated regulatory system rather than independent predictors, implying that PjBL effectiveness may stem from holistic activation of SRL rather than isolated strategy effects. Accordingly, SRL is best modeled as a latent construct mediating instructional influences on learning outcomes [2] [11] [16].

Within the SRL framework, planning represents the forethought phase in which learners set goals, anticipate task requirements, and organize strategies prior to engaging in learning activities [19]. Planning enables students to clarify objectives, allocate cognitive resources, and sequence actions needed to complete complex tasks. In project-based learning (PjBL) environments, planning is particularly critical because projects typically involve multi-step processes, extended timelines, and interdependent subtasks [16] [20]. Students must determine how to approach design problems, identify relevant knowledge and tools, and coordinate activities across project stages. Effective planning therefore supports structured engagement with project demands and reduces cognitive overload during task execution. Self-checking represents the monitoring and self-evaluation component of self-regulated learning during task performance [21] [22]. It refers to learners' active efforts to verify understanding, detect errors, and evaluate the correctness and adequacy of their work while learning activities are ongoing. Cognitive strategy use refers to learners' deliberate application of mental processes to understand, organize, and transform information during learning tasks [23]. In PjBL environments, cognitive strategy use becomes particularly salient because students must interpret complex task requirements, synthesize conceptual and procedural knowledge, and translate ideas into

workable designs or solutions. This study addresses these gaps by investigating how project-based learning and self-regulated learning strategies jointly relate to HOTS outcomes in an undergraduate analog electronics course. Empirical research consistently demonstrates that cognitive strategy use is associated with deeper learning outcomes and conceptual understanding [24]. Therefore, cognitive strategy use in this study is conceptualized as a reflective indicator of the broader SRL construct, representing learners' capacity to engage in meaningful knowledge processing during project-based learning. Specifically, SRL is conceptualized as a latent construct reflected by planning, cognitive strategy use, and self-checking [25].

2 THEORETICAL REVIEW

2.1 Project-based learning in engineering education and self-regulated learning context

Project-based learning is a learner-centered instructional approach in which knowledge acquisition is organized around complex, authentic projects that require sustained inquiry, design, and problem solving [5] [16]. Unlike conventional instruction that often emphasizes transmission of content, PjBL situates learning within real-world contexts where students actively construct understanding through exploration, experimentation, and iterative refinement. In engineering education, this approach aligns closely with professional practice, as engineers typically engage in project-oriented tasks involving system design, testing, and optimization [26], and has therefore been widely adopted to develop applied knowledge and transferable competencies.

The pedagogical effectiveness of PjBL is often attributed to its capacity to promote active engagement and meaningful learning processes [27] [28]. Project activities require learners to analyze requirements, integrate multidisciplinary knowledge, and evaluate alternative solutions, thereby supporting conceptual mastery and problem-solving ability. Beyond cognitive engagement, PjBL also shifts responsibility for learning to students, who must plan approaches, manage resources, and evaluate progress across project cycles. Such distributed responsibility naturally elicits SRL behaviors, positioning PjBL not only as a pedagogical approach but also as a contextual driver of regulatory processes.

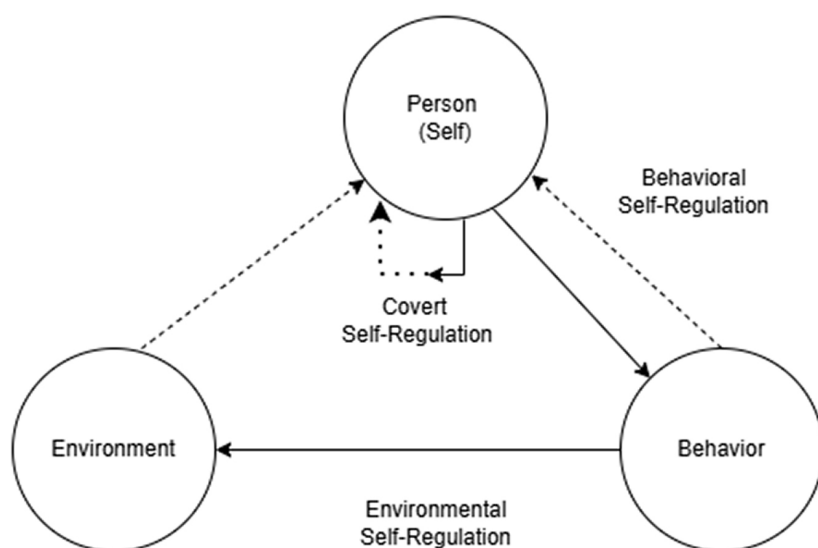


Fig. 1. Adapted triadic model of self-regulated learning based on social-cognitive theory [29]

Project-based learning environments can be theoretically understood through the lens of SRL as a dynamic interaction among personal, behavioral, and environmental factors. Figure 1 synthesizes major SRL frameworks and highlights a triadic reciprocal model derived from social-cognitive theory, in which regulation emerges from continuous interactions between the learner (person), learning actions (behavior), and instructional context (environment) [29]. In this model, self-regulation is not a static individual trait but a situated process shaped by task demands and learning conditions. Within project-based learning, the instructional environment represents authentic tasks, collaborative structures, and project constraints that require sustained inquiry and decision-making. These environmental characteristics directly influence learners' behavioral regulation, such as strategy use, persistence, and monitoring during project work. At the same time, learners' personal characteristics such as prior knowledge, motivation, and metacognitive awareness shape how they interpret and respond to project demands [29]. PjBL can therefore be conceptualized as an environmental driver that activates SRL processes. In the present study, SRL, reflected by planning, cognitive strategy use, and self-checking, represents the behavioral mechanism through which PjBL influences higher-order thinking outcomes, providing the theoretical basis for modeling SRL as the mediator linking PjBL and HOTS development.

2.2 Self-regulated learning frameworks

Self-regulated learning refers to learners' active process of setting goals, applying strategies, monitoring progress, and regulating cognition and behavior to achieve learning objectives [7] [8]. Rooted in social-cognitive theory, SRL conceptualizes learners as proactive agents who can control their thoughts, actions, and motivation within learning contexts [28] [26]. Consequently, regulation is considered a central mechanism underlying deep learning and complex skill acquisition. Major SRL frameworks conceptualize regulation as a cyclical process consisting of forethought, performance, and self-reflection phases. Learners plan strategies during forethought, implement and monitor cognition during performance, and evaluate outcomes during self-reflection. These iterative cycles are particularly important in complex, extended learning environments such as PjBL, where tasks are ill-structured and require sustained engagement.

2.3 Higher-order thinking skills and the relationship among project-based learning and self-regulated learning

Higher-order thinking skills refer to advanced cognitive processes involving analysis, evaluation, synthesis, and complex problem solving [18]. In engineering education, HOTS are essential because professional practice requires diagnosing system behavior, evaluating design alternatives, and optimizing solutions under constraints. Instructional approaches that foster HOTS are therefore critical for preparing students for authentic engineering tasks.

Higher-order thinking skills development is closely linked to learners' regulation of cognitive and metacognitive processes. SRL provides the mechanism through which learners plan approaches, apply cognitive strategies, and monitor understanding during complex tasks. Planning supports goal-directed reasoning, cognitive strategy use facilitates knowledge integration, and self-checking enables verification

and refinement. Through coordinated regulation, learners sustain deep processing and iterative improvement, which underpin higher-order thinking. Empirical evidence across STEM contexts shows that SRL predicts conceptual understanding and problem-solving performance, indicating its central role in HOTS development.

Table 1. Theoretical constructs and indicators in the study

Construct	Definition	Theoretical Basis	Indicators in this Study	Role in Model
Project-Based Learning (PjBL) [30]	Learner-centered instructional approach organized around authentic projects and sustained inquiry.	Constructivist learning theory; experiential learning; engineering education pedagogy	Learning condition (PjBL vs. conventional)	Exogenous variable
Self-Regulated Learning (SRL) [31]	Learners' regulation of planning, cognitive strategy use, and monitoring during learning tasks.	Social-cognitive theory of SRL; Panadero (2017); Zimmerman cyclical model	Planning, Cognitive Strategy, Self-Checking	Latent mediating construct
Higher-Order Thinking Skills (HOTS) [28]	Advanced cognitive processes involving analysis, evaluation, and complex problem solving.	Revised Bloom's taxonomy; complex cognition in STEM learning	HOTS Gain, Posttest HOTS	Endogenous outcome
Baseline HOTS [3]	Learners' prior level of higher-order thinking before instructional intervention.	Prior knowledge theory; baseline achievement effects	Pretest HOTS	Control variable

3 RESEARCH METHOD

3.1 Research design

This study employed a quasi-experimental pretest–posttest control group design to examine how PjBL and SRL relate to HOTS in an undergraduate engineering course [5] [3] [7]. Students were assigned to either a PjBL class or a conventional lecture-based class with equivalent learning objectives and assessments, enabling comparison of instructional effects while controlling for baseline ability through pretest scores.

The PjBL group engaged in structured projects involving circuit design, simulation, testing, and iterative refinement, requiring planning, strategic reasoning, and self-checking behaviors characteristic of SRL. The conventional group received lecture-based instruction and guided exercises emphasizing conceptual and procedural understanding. Both classes were delivered during the same academic period with identical learning outcomes to ensure instructional comparability. Participants consisted of 50 undergraduate engineering students (25 PjBL; 25 conventional) with comparable demographic and educational backgrounds. Most participants were aged 17–20 years and reported frequent daily use of digital technologies, reflecting typical characteristics of contemporary engineering learners. Demographic

distributions across gender, age, technology use, residence, and school background were similar between groups, supporting the validity of subsequent instructional comparisons. Participant characteristics are presented in Table 2.

Table 2. Participant category frequencies

Characteristic	Category	1PjBL (n = 25)	Conventional (n = 25)	Total (n = 50)
Gender	Male	15	16	31
Gender	Female	10	9	19
Age	17–18	9	4	13
Age	19–20	14	17	31
Age	21–22	2	3	5
Age	23–24	0	1	1
Internet use per day	1–3 hours	1	2	3
Internet use per day	4–6 hours	6	10	16
Internet use per day	7–9 hours	11	6	17
Internet use per day	>10 hours	7	7	14
Smartphone use per day	1–3 hours	1	1	2
Smartphone use per day	4–6 hours	8	7	15
Smartphone use per day	7–9 hours	8	10	18
Smartphone use per day	>10 hours	8	7	15
Residence	Regency	4	7	11
Residence	City	21	18	39
School background	Islamic Senior High School	0	2	2
School background	General Senior High School	12	12	24
School background	Vocational Senior High School	13	11	24

3.2 Research model design and hypotheses development

This study employed a quasi-experimental pretest–posttest control group design to examine the effects of PjBL and SRL on students' HOTS in an undergraduate engineering course. Two intact classes received different instructional approaches: a PjBL class and a conventional lecture-based class [1] [7] [16]. Both groups completed equivalent learning objectives and assessments, allowing evaluation of instructional effects while controlling for baseline HOTS performance [3].

The experimental design involved measuring students' HOTS prior to instruction (pre-test), implementing different instructional treatments, and assessing HOTS after instruction (post-test). The PjBL group engaged in structured projects involving circuit design, simulation, testing, and iterative refinement, intended to activate planning, cognitive strategy use, and self-checking behaviors characteristic of

self-regulated learning. The conventional group received lecture-based instruction and guided exercises emphasizing conceptual and procedural understanding. Both groups were taught within the same academic period and duration to ensure comparable exposure.

Within this framework, instructional condition (PjBL vs. conventional) served as the exogenous variable. SRL, reflected by planning, cognitive strategy use, and self-checking, was modeled as a latent mediator representing regulatory engagement during learning. HOTS were operationalized through HOTS gain (pre-test–post-test improvement) and post-test HOTS (final performance), with baseline HOTS (pre-test) included as a control variable influencing post-test outcomes. This structure enabled simultaneous examination of instructional effects, regulatory processes, and learning outcomes within a structural modeling framework [13].

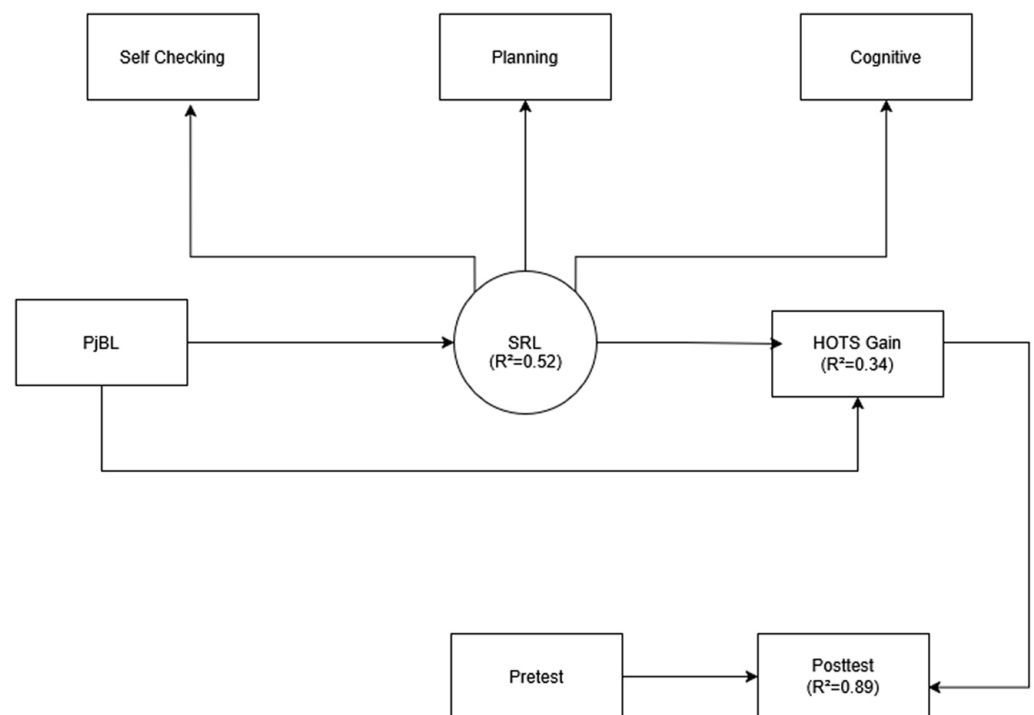


Fig. 2. Research model design

The structural model examines the mechanism through which PjBL influences HOTS via SRL. SRL is specified as a central mediating construct reflected by planning, cognitive strategy use, and self-checking, while PjBL functions as an exogenous instructional predictor of SRL. The strong path from PjBL to SRL ($\beta = 0.72$) indicates that participation in project-based learning substantially enhances students' regulatory engagement. SRL, in turn, predicts HOTS gain ($\beta = 0.11$), representing improvement in higher-order thinking from pretest to posttest. The model explains a moderate proportion of variance in HOTS gain ($R^2 = 0.34$). High factor loadings for planning (0.88), cognitive strategy use (0.91), and self-checking (0.86) confirm that these strategies coherently represent SRL as an integrated regulatory construct.

Baseline HOTS (pre-test) strongly predicts post-test HOTS ($\beta = 0.90$), which further contributes to HOTS gain ($\beta = 0.25$). The high explained variance in post-test HOTS ($R^2 = 0.89$) indicates that prior ability and instructional effects jointly account for most outcome variability. Overall, the model supports a mediated learning mechanism in which PjBL enhances HOTS primarily through activation of SRL while

controlling for prior knowledge. PjBL environments require learners to set goals, plan tasks, apply strategies, and monitor progress; therefore, PjBL is expected to positively predict SRL. SRL facilitates deep cognitive processing and adaptive strategy use during complex tasks, leading to greater HOTS improvement. SRL is manifested through planning (forethought), cognitive strategy use (performance), and self-checking (self-reflection). Prior knowledge predicts post-test HOTS, which subsequently contributes to HOTS gain. Because PjBL primarily operates through regulatory engagement, its effect on HOTS gain is expected to occur indirectly via SRL. The resulting research hypotheses are presented in Table 3.

Table 3. Research hypotheses

Hypothesis	Path	Theoretical Rationale
H1	PjBL → SRL	Project-based learning promotes regulatory engagement
H2	SRL → HOTS Gain	Self-regulation leads to greater cognitive improvement
H3	SRL → Planning	Planning reflects forethought phase of SRL
H4	SRL → Cognitive Strategy	Cognitive strategy represents strategic processing
H5	SRL → Self-Checking	Self-checking reflects monitoring and evaluation
H6	Pretest → Posttest	Prior knowledge predicts final performance
H7	Posttest → HOTS Gain	Final achievement contributes to gain
H8	PjBL → HOTS Gain (indirect via SRL)	PjBL improves HOTS through SRL mediation

4 RESULTS AND DISCUSSIONS

4.1 Group differences

Descriptive statistics and independent-samples t-tests compared the PjBL and conventional groups across baseline HOTS, post-instruction outcomes, and self-regulated learning components (refer to Table 4). Prior to instruction, the groups did not differ significantly in HOTS ($t = 0.71$, $p = .479$, $d = 0.20$), indicating comparable baseline cognitive ability and supporting the validity of subsequent outcome comparisons.

Table 4. Descriptive statistics, group comparisons, and effect sizes result

Variable	PjBL (T) Mean (SD)	Conventional (C) Mean (SD)	t	p	Cohen's d
Pretest HOTS	69.32 (9.24)	67.56 (8.19)	0.71	0.479	0.20
Posttest HOTS	75.00 (9.64)	70.20 (6.87)	2.03	0.049	0.57
Normalised gain (g)	0.20 (0.12)	0.08 (0.09)	4.25	0.000	1.20
Planning	4.80 (0.25)	3.74 (0.96)	5.32	0.000	1.50
Cognitive strategy	4.75 (0.19)	3.75 (0.93)	5.26	0.000	1.49
Self-checking	4.82 (0.24)	3.88 (0.92)	4.94	0.000	1.40

After the intervention, significant differences favored the PjBL group. Students in the PjBL condition achieved higher posttest HOTS scores ($M = 75.00$, $SD = 9.64$)

than those in the conventional group ($M = 70.20$, $SD = 6.87$), with a moderate effect ($t = 2.03$, $p = .049$, $d = 0.57$). Larger differences were observed in normalized HOTS gain, where the PjBL group showed substantially greater improvement ($M = 0.20$, $SD = 0.12$) than the conventional group ($M = 0.08$, $SD = 0.09$), yielding a large effect ($t = 4.25$, $p < .001$, $d = 1.20$). These results indicate that PjBL enhanced both final performance and learning progress. Significant group differences were also found across all self-regulated learning components. The PjBL group reported higher planning ($M = 4.80$ vs. 3.74 ; $t = 5.32$, $p < .001$, $d = 1.50$), cognitive strategy use ($M = 4.75$ vs. 3.75 ; $t = 5.26$, $p < .001$, $d = 1.49$), and self-checking ($M = 4.82$ vs. 3.88 ; $t = 4.94$, $p < .001$, $d = 1.40$), all with large effects. Overall, while groups were initially equivalent, PjBL produced substantially higher SRL engagement and greater HOTS gains, supporting the link between regulatory processes and higher-order thinking improvement.

4.2 Structural model results

The model explained moderate variance in SRL ($R^2 = 0.52$) and HOTS gain ($R^2 = 0.34$), while posttest HOTS was strongly predicted by prior ability ($R^2 = 0.89$), indicating satisfactory explanatory power. PjBL showed a strong positive effect on SRL ($\beta = 0.72$), demonstrating that project-based instruction substantially increased students' engagement in planning, cognitive strategy use, and self-checking. SRL had a positive but modest direct effect on HOTS gain ($\beta = 0.11$), suggesting that regulatory engagement contributed to higher-order thinking improvement with limited unique influence. A direct PjBL $\rightarrow$ HOTS gain effect was also observed ($\beta = 0.42$), indicating partial mediation: PjBL enhanced HOTS both through SRL and through additional instructional mechanisms such as authentic task engagement and problem-solving demands.

Baseline HOTS strongly predicted post-test HOTS ($\beta = 0.90$), while post-test HOTS further contributed to HOTS gain ($\beta = 0.25$), supporting a developmental link between prior knowledge, final performance, and learning improvement. Overall, the results confirm that PjBL promotes higher-order thinking through both regulatory engagement and direct instructional effects, with SRL as a central but not exclusive mechanism.

4.3 Multicollinearity diagnostics

Multicollinearity diagnostics were performed to examine the degree of intercorrelation among the predictor variables included in the regression and structural models. The variance inflation factor (VIF) values for each predictor are reported in Table 5.

Table 5. VIF values result

Predictor	VIF
cognitive_strategy	10.23
self_checking	7.51
planning	7.50
group_T	1.62
Pretest	1.03

The three SRL components cognitive strategy, self-checking, and planning showed high multicollinearity ($VIF > 5$), indicating substantial shared variance and conceptual overlap within the broader self-regulated learning construct. In contrast, the instructional group variable and pretest HOTS exhibited low VIF values, suggesting independent contributions to the outcome models. The elevated intercorrelation among SRL indicators implies that their unique regression effects are attenuated when entered simultaneously. Therefore, SRL was modeled as a latent composite construct in the final structural model, allowing shared variance among its indicators to be represented explicitly. This approach supports conceptualizing SRL as a unified regulatory process while retaining PjBL and prior HOTS as distinct predictors of learning outcomes.

5 DISCUSSION

This study examined how PjBL and SRL contribute to HOTS in undergraduate engineering education. The findings indicate that PjBL significantly enhances students' regulatory engagement and produces greater HOTS improvement than conventional instruction. Structural analysis confirms that SRL functions as a mediating mechanism linking instructional design and cognitive development, while prior knowledge remains the strongest predictor of final performance. The strong effect of PjBL on SRL (H1 supported) shows that authentic project environments stimulate planning, cognitive strategy use, and self-checking behaviors, consistent with social-cognitive SRL theory. SRL demonstrated a positive but modest direct effect on HOTS gain (H2 partially supported), indicating that regulatory engagement contributes to improvement but operates jointly with instructional design. The strong interdependence among SRL components further supports regulation as an integrated system rather than isolated strategies. Measurement results confirmed planning, cognitive strategy use, and self-checking as coherent indicators of SRL (H3–H5 supported). Baseline HOTS strongly predicted posttest HOTS (H6 supported), highlighting the stability of higher-order reasoning, while posttest HOTS contributed to HOTS gain (H7 supported), indicating that learning growth translates into achievement. Overall, PjBL enhanced HOTS partly through SRL (H8 partially supported). These findings support the view that effective instructional design operates through both environmental affordances and learner regulation.

Theoretically, this study strengthens the integration of SRL theory with constructivist instructional design by establishing PjBL as an environmental driver of regulatory processes that support higher-order cognition. Practically, engineering instruction should incorporate structured projects with milestones, reflection prompts, and iterative evaluation to foster SRL and HOTS, while scaffolding should align with students' initial reasoning levels. Limitations include the small sample size, single-course context, and reliance on self-report SRL measures. Future research should examine larger samples, multiple engineering domains, and additional mediators such as collaboration or motivation to clarify the full pathway through which PjBL enhances higher-order thinking. Overall, the findings confirm that project-based learning promotes HOTS through both regulatory engagement and direct instructional mechanisms.

6 CONCLUSION

This study provides empirical evidence explaining how PjBL promotes HOTS through SRL processes in undergraduate engineering education. The findings show

that PjBL significantly enhances students' regulatory engagement, including planning, cognitive strategy use, and self-checking, which in turn supports HOTS improvement. Structural modeling confirms that SRL functions as a mediating mechanism linking instructional environment and cognitive gain, while PjBL also exerts a direct effect on HOTS. These results indicate that the effectiveness of PjBL derives from both authentic task engagement and activation of learners' regulatory processes. The study also confirms the dominant influence of baseline HOTS on post-instruction performance, highlighting the stability of higher-order reasoning while demonstrating that instructional experiences can still produce measurable cognitive growth. Overall, HOTS development emerges from the interaction among instructional design, regulatory engagement, and prior knowledge. Theoretically, this study extends SRL theory in engineering education by establishing SRL as the central behavioral mechanism through which PjBL environments influence higher-order cognition.

7 REFERENCES

- [1] F. A. Darmawan and A. Jaedun, "Mediation effect of assessment as learning in mobile-based module on vocational education students HOTS," *J. Educ. Sci. Technol.*, vol. 6, no. 1, pp. 32–39, 2020. <https://doi.org/10.26858/est.v6i1.11437>
- [2] I. R. Suwarma and S. Apriyani, "Explore teachers' skills in developing lesson plan and assessment that oriented on higher order thinking skills (HOTS)," *J. Innov. Educ. Cult. Res.*, vol. 3, no. 2, pp. 106–113, 2022. <https://doi.org/10.46843/jiecr.v3i2.66>
- [3] D. Li, X. Fan, and L. Meng, "Development and validation of a higher-order thinking skills (HOTS) scale for major students in the interior design discipline for blended learning," *Sci. Rep.*, vol. 14, no. 1, Art. no. 20287, 2024. <https://doi.org/10.1038/s41598-024-70908-3>
- [4] H. Kuo, "STEAM PBL as an educational panacea? Investigating its impact on creative thinking and academic achievement across subjects," *Think. Ski. Creat.*, vol. 60, no. 1, p. 102072, 2026. <https://doi.org/10.1016/j.tsc.2025.102072>
- [5] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, "Motivating project-based learning: Sustaining the doing, supporting the learning," *Educational Psychologist*, vol. 26, nos. 3–4, pp. 369–398, 1991. <https://doi.org/10.1080/00461520.1991.9653139>
- [6] N. Ozdamar-Keskin, F. Z. Ozata, K. Banar, and K. Royle, "Examining digital literacy competences and learning habits of open and distance learners," *Contemp. Educ. Technol.*, vol. 6, no. 1, pp. 74–90, 2020. <https://doi.org/10.30935/cedtech/6140>
- [7] R. M. Isaacson and F. Fujita, "Metacognitive knowledge monitoring and self-regulated learning: Academic success and reflections on learning," *Journal of the Scholarship of Teaching and Learning*, vol. 6, no. 1, pp. 39–55, 2006.
- [8] O. Heaysman and B. Otto, "Editorial: Fostering self-regulated learning," *Front. Psychol.*, vol. 16, p. 1681074, 2025. <https://doi.org/10.3389/fpsyg.2025.1681074>
- [9] P. H. Winne and A. F. Hadwin, "Studying as self-regulated learning," in *Metacognition in Educational Theory and Practice*, D. J. Hacker, J. Dunlosky, and A. C. Graesser, Eds., Mahwah, NJ, USA: Lawrence Erlbaum Associates, 1998, pp. 277–304.
- [10] C. Ramos-Galarza, J. Obregón, N. Lepe-Martínez, M. Del Valle, B. Guerrero-Tates, and J. Cruz-Cárdenas, "Cognitive and emotional predictors of self-regulated learning: A structural model based on executive functions, learning strategies, and sense of coherence," *Int. J. Educ. Res. Open*, vol. 9, Art. no. 100528, 2025. <https://doi.org/10.1016/j.ijedro.2025.100528>

- [11] N. Ishartono, A. Dessty, H. J. Prayitno, and Y. Sidiq, "The quality of HOTS-based science questions developed by Indonesian elementary school teachers," *J. Educ. Technol.*, vol. 5, no. 2, pp. 236–245, 2021. <https://doi.org/10.23887/jetv5i2.33813>
- [12] E. Tasrif *et al.*, "The contribution of smartphone learning models on student academic performance: The role of mediating effects," *Int. J. Inf. Educ. Technol.*, vol. 14, no. 10, pp. 1453–1460, 2024. <https://doi.org/10.18178/ijiet.2024.14.10.2176>
- [13] C. Q. Nguyen, A. M. T. Nguyen, and L. B. Le, "Using partial least squares structural equation modeling (PLS-SEM) to assess the effects of entrepreneurial education on engineering students' entrepreneurial intention," *Cogent Educ.*, vol. 9, no. 1, Art. no. 2122330, 2022. <https://doi.org/10.1080/2331186X.2022.2122330>
- [14] N. L. Higgins, J. A. Rathner, and S. Frankland, "Development of self-regulated learning: A longitudinal study on academic performance in undergraduate science," *Res. Sci. Technol. Educ.*, vol. 41, no. 4, pp. 1242–1266, 2023. <https://doi.org/10.1080/02635143.2021.1997978>
- [15] E. Panadero, A. Jonsson, L. Pinedo, and B. Fernández-Castilla, "Effects of rubrics on academic performance, self-regulated learning, and self-efficacy: A meta-analytic review," *Educ. Psychol. Rev.*, vol. 35, no. 4, Art. no. 113, 2023. <https://doi.org/10.1007/s10648-023-09823-4>
- [16] A. Agni, M. Giatman, M. Agni, A. Agni, and S. Islami, "Enhancing critical thinking and teamwork through AI-integrated project-based learning in engineering education," *JOIV: International Journal on Informatics Visualization*, vol. 10, no. 1, pp. 94–104, 2026. <https://doi.org/10.62527/joiv.10.1.3515>
- [17] H. Novianti, "Building independent learners: The role of guidance and counseling in developing self-regulated learning," in *Proc. International Conference UPI-UPSI*, vol. 1, 2025, pp. 7–19.
- [18] S. Otto, R. Lavi, and L. B. Bertel, "Human-GenAI interaction for active learning in STEM education: State-of-the-art and future directions," *Comput. Educ.*, vol. 239, Art. no. 105444, 2025. <https://doi.org/10.1016/j.compedu.2025.105444>
- [19] M. Anwar, "Analysis of vocational interests and student's perception of work-based on society 5.0 towards learning outcomes," *JPPi (Jurnal Penelit. Pendidik. Indones.)*, vol. 7, no. 1, pp. 57–64, 2021. <https://doi.org/10.29210/02021845>
- [20] M. Sirwesvary and K. A. Jamaludin, "Implementations of project based learning in primary schools," *International Journal of Academic Research in Progressive Education and Development*, vol. 14, no. 1, pp. 206–223, 2025. <https://doi.org/10.6007/IJARPED/v14-i1/24282>
- [21] D. Sumarsono *et al.*, "The association between self-regulated learning and writing achievement in a blended learning environment: The possible predictors," *Teaching English Language*, vol. 20, no. 1, pp. 179–214, 2026.
- [22] G. Supriyanto, I. Widiaty, A. G. Abdullah, and Y. R. Yustiana, "Application expert system career guidance for students," *J. Phys. Conf. Ser.*, vol. 1402, no. 6, Art. no. 066031, 2019. <https://doi.org/10.1088/1742-6596/1402/6/066031>
- [23] K. T. Kim, "The structural relationship among digital literacy, learning strategies, and core competencies among South Korean college students," *Educ. Sci. Theory Pract.*, vol. 19, no. 2, pp. 3–21, 2019. <https://doi.org/10.12738/estp.2019.2.001>
- [24] R. Febrianti, A. Yufrizal, R. P. Putra, and P. Phongdala, "Implementation of project-based learning for improve students' critical thinking skills in creative product and entrepreneurship subjects," *Jurnal Pendidikan Teknologi Kejuruan*, vol. 6, no. 4, pp. 240–247, 2023. <https://doi.org/10.24036/jptk.v6i4.34523>

- [25] J. M. Marquès Puig, T. Daradoumis, M. Arguedas, and L. Calvet Liñan, "Using a distributed systems laboratory to facilitate students' cognitive, metacognitive, and critical-thinking strategy use," *J. Comput. Assist. Learn.*, vol. 38, no. 1, pp. 209–222, 2022. <https://doi.org/10.1111/jcal.12605>
- [26] M. Anwar, T. Taali, H. Hidayat, and E. Sabrina, "Exploring trait thinking in predicting students' higher-order thinking skills (HOTS) using ANFIS: A study on electronics engineering education students," *TEM Journal*, vol. 13, no. 4, pp. 3103–3111, 2024. <https://doi.org/10.18421/TEM134-45>
- [27] M. I. Qureshi *et al.*, "A systematic review of past decade of mobile learning: What we learned and where to go," *International Journal of Interactive Mobile Technologies (ijIM)*, vol. 14, no. 6, pp. 67–81, 2020. <https://doi.org/10.3991/ijim.v14i06.13479>
- [28] Y. Hendriyani, M. Anwar, H. Hidayat, and E. Sabrina, "Predicting academic performance based on students' HOTS, cognitive structure, prior knowledge, and trait thinking using ANFIS model," *TEM Journal*, vol. 14, no. 3, pp. 2402–2410, 2025. <https://doi.org/10.18421/TEM143-45>
- [29] E. Panadero, "A review of self-regulated learning: Six models and four directions for research," *Front. Psychol.*, vol. 8, Art. no. 422, 2017. <https://doi.org/10.3389/fpsyg.2017.00422>
- [30] M. Anwar, Y. Rahmawati, N. Yuniarti, H. Hidayat, and E. Sabrina, "Leveraging augmented reality to cultivate higher-order thinking skills and enhance students' academic performance," *Int. J. Inf. Educ. Technol.*, vol. 14, no. 10, pp. 1405–1413, 2024. <https://doi.org/10.18178/ijiet.2024.14.10.2171>
- [31] Y. Zhao *et al.*, "Computers & education a meta-analysis of the correlation between self-regulated learning strategies and academic performance in online and blended learning environments," *Comput. Educ.*, vol. 230, Art. no. 105279, 2025. <https://doi.org/10.1016/j.compedu.2025.105279>

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