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Advancing Metacognitive Competencies in Engineering Education: A Scaffolding Project-Based Learning (SFPjBL) Approach

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ABSTRACT

Engineering education is undergoing a paradigm shift in response to Industry 5.0, emphasizing the need for higher-order cognitive competencies beyond mere technical skills. This study investigates the effectiveness of Scaffolding Project-Based Learning (SPjBL), an instructional approach integrating Phased Guidance (PG), Timely Feedback (TF), and Reflective Activities (RA), in enhancing engineering students' metacognitive regulation—particularly in planning, monitoring, and evaluation. Utilizing a mixed-methods design, this research involved first-year electrical engineering students at a Malaysian university participating in a 12-week "Mini Home Getaway Electrical Design" project. Quantitative results from the Metacognitive Awareness Inventory (MAI) indicated significant improvements in information management ($p < 0.000$), evaluation skills ($p < 0.015$), and procedural knowledge ($p < 0.049$). Qualitative analysis of 132 reflective entries showed predominantly positive, objective responses highlighting effective knowledge and task management, though students exhibited limited reflective depth in evaluation-related aspects. Among scaffolding strategies, Timely Feedback was particularly effective in supporting real-time monitoring and self-adjustments, while Phased Guidance facilitated early project planning but showed decreased utility in later stages. Reflective Activities demonstrated potential yet required optimization to enhance deeper evaluative reflection. The findings underscore the practical significance of scaffolding interventions in fostering self-regulated learning within engineering education contexts. Future research is recommended to refine reflective activities, possibly extending the intervention duration, to further validate and enhance the long-term efficacy of the SPjBL model for diverse educational environments.

Keywords: Scaffolding Project-Based Learning (SPjBL); metacognitive regulation; reflective activities; self-regulated learning; engineering education

INTRODUCTION

With the advent of the Industry 5.0 era, engineering education faces new challenges and opportunities. This era, characterized by human-machine collaboration and intelligent automation, demands more than just technical expertise. Students must also develop higher-order cognitive skills, such as critical thinking, problem-solving, and self-regulation, to adapt to rapidly evolving technological environments and complex engineering tasks (Lavado-Anguera et al. 2024).

Traditional teacher-centered instructional models are gradually being replaced by student-centered pedagogies, emphasizing active learning and experiential learning to cultivate well-rounded competencies. Among these approaches, Project-Based Learning (PjBL) has proven to be an effective instructional strategy, immersing students in authentic problem-solving scenarios that integrate theoretical knowledge with practical applications, thereby enhancing their technical proficiency and professional competence (Prince, 2004). In engineering education, PjBL is widely employed to simulate real-world engineering projects, such as circuit design, system optimization, and prototyping, enabling students to acquire domain-specific skills through hands-on experiences.

While general Project-Based Learning (PjBL) immerses students in real-world tasks to enhance technical competencies, it often lacks explicit mechanisms to support the development of higher-order cognitive skills such as planning, monitoring, and evaluation. The unique contribution of Scaffolding Project-Based Learning (SPjBL), as introduced in this study, lies in its deliberate integration of structured scaffolding strategies: Phased Guidance (PG), Timely Feedback (TF), and Reflective Activities (RA). These targeted supports systematically foster students' metacognitive regulation abilities throughout project phases, directly addressing self-regulation challenges typically encountered but inadequately supported by traditional PjBL.

However, despite its pedagogical potential, PjBL presents inherent challenges due to its complexity and open-ended nature. PjBL typically involves multi-step tasks, interdisciplinary knowledge integration, and self-directed learning, all of which demand strong self-regulation from students (Guo et al. 2020). In particular, metacognitive skills—the ability to plan, monitor, and evaluate one's learning process—are critical in navigating such learning environments (Schraw & Dennison, 1994). Students lacking metacognitive strategies often struggle with resource allocation, progress tracking, and self-reflection, leading to suboptimal learning outcomes or even project failure.

Research indicates that metacognitive regulation is not only a key determinant of academic success but also a fundamental enabler of innovation and problem-solving in engineering practice (Flavell 1979). Therefore, supporting students in developing metacognitive skills within PjBL has become a crucial research focus in engineering education.

Scaffolding Theory provides a theoretical foundation for addressing this challenge. Rooted in Vygotsky's Zone of Proximal Development (ZPD), this theory emphasizes structured external support to help students bridge the gap between their current and potential capabilities, ultimately fostering independent learning (Vygotsky & Cole 1978) as shown in Figure 1.

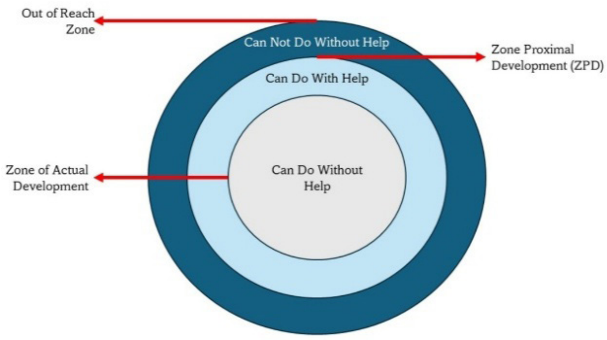

FIGURE 1. Zone Proximal Development

In educational practice, scaffolding can take the form of phased task guidance, real-time feedback mechanisms, and reflective activities, which reduce cognitive load and gradually enhance students' self-regulatory skills (Wood et al. 1976). The integration of Scaffolding Theory with PjBL gives rise to Scaffolding Project-Based Learning (SPjBL), a pedagogical approach that optimizes students' learning experiences through dynamic support mechanisms, particularly in the development of metacognitive skills.

This study contributes to both theory and practice. Theoretically, it validates Scaffolding Theory within engineering education, enriching research on the intersection of PjBL and metacognitive development. Practically, the findings offer empirical insights for instructional design in engineering education, aiming to address self-regulation challenges in PjBL environments. By optimizing scaffolding strategies, educators can provide more effective support for students in tackling complex engineering tasks, thereby enhancing their technical expertise, higher-order cognitive skills, and lifelong learning capabilities, ultimately preparing them to be innovative engineers in the Industry 5.0 era.

METHODOLOGY

This study aims to evaluate the impact of Scaffolding Project-Based Learning (SPjBL) on the development of metacognitive skills among engineering students. A mixed-methods design was employed, integrating quantitative and qualitative data analysis to provide comprehensive empirical evidence (Creswell & Clark, 2017). The study was conducted in a first-year electrical engineering course at a Faculty of Electrical Engineering (FKE) at a Malaysian university, with 44 students participating. These students were divided into groups and tasked with completing the

Mini Home Getaway Electrical Design project, designed to simulate authentic engineering tasks and enhance students' technical competencies, self-regulation, and metacognitive skills (i.e., planning, monitoring, and evaluation) (Prince 2004).

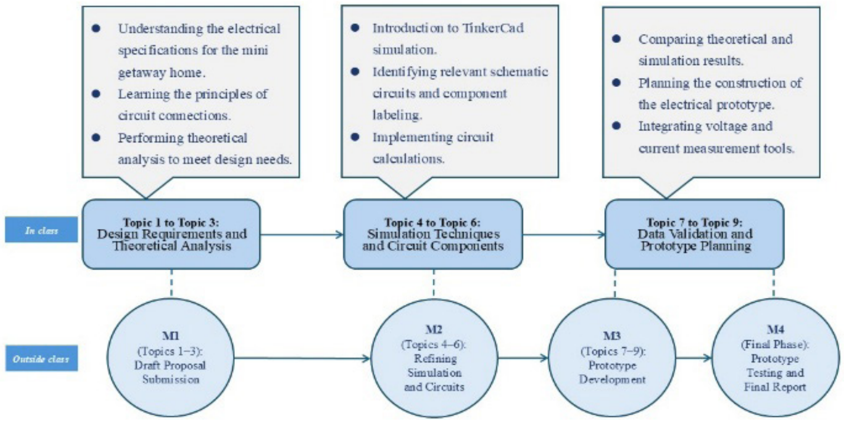

FIGURE 2. Project Implementation

As can be seen in Figure 2, the project was divided into three phases: Project Proposal, Project Demonstration, and Final Report.

In the first phase, which was implemented from Week 1 to Week 4, a needs analysis was conducted, design objectives were formulated, and a proposal was submitted. This proposal included the problem definition, circuit design principles, and preliminary resource planning.

During the second phase. Which was carried out from Week 5 to Week 8, TinkerCad was used to test the designs. This phase was followed by oral presentations, where the students showcased their designs and preliminary outcomes to peers and instructors.

The final phase, conducted from Week 9 to Week 12, required students to refine their designs based on feedback, develop physical prototypes, and submit a comprehensive project report. The final presentation included a reflection on the design process and evaluation of technical outcomes.

The complexity of this project was attributed to its multi-step nature, interdisciplinary knowledge integration (e.g., electrical engineering and sustainable design), and self-regulated problem-solving, which posed significant demands on students' metacognitive skills (Guo et al. 2020). To support students throughout this process, three scaffolding interventions as listed in Table 1 were introduced, designed to dynamically adjust support intensity based on Vygotsky's Zone of Proximal Development (ZPD) (Vygotsky & Cole, 1978). The aim was to gradually reduce external support, fostering independent learning (Wood et al. 1976).

TABLE 1. Scaffolding interventions

Scaffolding Interventions	Description
Phased Guidance (PG)	*Objective:* To clarify task direction, reduce cognitive load, and improve planning abilities. *Implementation:* The project was decomposed into manageable sub-goals, each phase featuring clearly defined milestones and structured guidance templates (e.g., a needs analysis template in Phase 1, and a simulation design checklist in Phase 2).
Timely Feedback (TF)	*Objective:* To enhance students' monitoring skills and enable timely strategy adjustments. *Implementation:* Real-time feedback was provided by instructors and peers at each phase. Examples include written feedback on proposals (Phase 1), oral feedback during presentations (Phase 2), and iterative prototype evaluation (Phase 3).

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Reflective Activities (RA)	*Objective:* To foster self-evaluation and develop students' ability to assess their learning progress (Flavell, 1979). *Implementation:* Students responded to reflective peer review questions at the end of each phase (e.g., "What challenges did you encounter in this phase?" "How did you adjust your strategy?").

To evaluate the impact of the educational intervention on students' metacognitive development within the context of the *Mini Home Gateway Electrical Design* project, qualitative data were collected. The aim is to capture a comprehensive understanding of students' cognitive engagement, self-regulatory skills, and reflective practices throughout the learning process. The focus was on how students applied metacognitive strategies within a project-based learning environment across multiple phases.

The qualitative data was obtained through open-ended reflective questions embedded within the peer review process. At each project phase, students responded to four to five reflective questions that encouraged them to articulate their experiences, identify challenges, and describe strategic adjustments they made. These narratives offered rich, contextual insights into the students' evolving metacognitive practices and provided a deeper understanding of how they navigated the complexities of collaborative learning.

DATA ANALYSIS

The analysis using qualitative methods is to provide a comprehensive understanding of how instructional scaffolds—Phased Guidance (PG), Timely Feedback (TF), and Reflective Activities (RA)—influence students' planning, monitoring, and evaluation abilities (Lavado-Anguera et al. 2024).

Qualitative data were examined using thematic and sentiment analysis (Braun & Clarke, 2006), which identified behavioral patterns and emotional tone in students' reflective responses. Cross-validation was employed to triangulate findings and ensure consistency between quantitative and qualitative results (Creswell & Clark 2017). Table 2 listed the process of the data analysis.

TABLE 2. Process of data analysis

Analysis Type	Method	Purpose
Qualitative Braun & Clarke (2006)	Thematic analysis	Identify key themes, behavioral patterns, and strategy use from reflective responses
	Sentiment analysis	Analyze emotional tone (polarity and subjectivity) in student reflections
	Cross-validation	Triangulate quantitative and qualitative results to enhance validity

RESULTS

THEMATIC AND SENTIMENT ANALYSIS OF REFLECTIVE DATA

This study conducted text analysis to explore students' reflective responses on the Mini Home Getaway Electrical Design project within Scaffolding Project-Based Learning (SPjBL) (Prince 2004). The goal was to evaluate the impact of Phased Guidance (PG), Timely Feedback (TF), and Reflective Activities (RA) on the development of metacognitive skills (Schraw & Dennison, 1994).

The dataset consisted of 132 open-ended reflective responses submitted by 44 students at the end of the three project phases (Proposal - P1, Demonstration - P2, and Final Report - P3).

The analysis utilized Natural Language Processing (NLP) techniques, employing the TextBlob library to compute Polarity (sentiment score) and Subjectivity (*(PDF) Natural Language Processing with Python*, n.d.). Additionally, manual coding was used to extract keywords, count their frequencies, and classify them into eight metacognition-related dimensions.

The sentiment analysis revealed that the average polarity of students' reflections was 0.074 (on a scale from -1 to 1), indicating a slightly positive sentiment (*(PDF) Natural Language Processing with Python*, n.d.). The subjectivity score was 0.228 (on a scale from 0 to 1), suggesting that students' evaluations were relatively objective.

These findings indicate that students' overall experience with Scaffolding Project-Based Learning

(SPjBL) was positive and rational, likely influenced by the supportive role of scaffolding strategies (Wood et al. 1976).

The keyword frequency analysis highlighted the key areas of focus in students' reflections, as shown in the Table 3 (Braun & Clarke 2006):

TABLE 3. Keyword frequencies and interpretations from students' reflective responses

Dimension	Keywords	Frequency	Interpretation
Knowledge Management	Aware, Know, Understand, etc.	128	The most frequently mentioned dimension, reflecting students' understanding and mastery of electrical design knowledge.
Task Management	Circuit Design, Soldering, Software Use, etc.	123	Indicates frequent references to specific task execution.
Planning	Planning, Goal Setting, Strategy Development, Task Allocation, etc.	49	Shows students' focus on tracking their learning process.
Information Management	Researching, Studying Skills, Note Organization, Information Gathering, etc.	59	Reflects frequent attempts at problem-solving.
Monitoring	Checking, Discussing, Reviewing, Assessing, etc.	87	Involves resource-handling behaviors.
Regulation	Debugging, Correcting, Troubleshooting, Solving, etc.	63	Demonstrates attention to task adjustments.
Regulatory Strategies	Switching, Selecting, Adapting to Context, etc.	42	Indicates mentions of strategy selection.
Evaluation	Self-Assessment, Reflection, Improvement, Evaluation, etc.	40	The least frequently mentioned dimension, suggesting relatively less emphasis on reflective evaluation.

The keyword frequency analysis is closely related to the three core functions of metacognition—planning, monitoring, and evaluation (Flavell 1979).

1. The Planning dimension (49 mentions) corresponds to the metacognitive planning function. Students frequently referenced goal setting and task allocation in their reflections, indicating that scaffolding strategies effectively supported task breakdown and planning formulation (Guo et al. 2020).
2. The high frequency of the Monitoring dimension (87 mentions) and Regulation dimension (63 mentions) reflects the metacognitive monitoring function. Students demonstrated continuous attention to their learning process through progress checking and circuit debugging, aligning with the complex circuit design and prototype testing requirements in the project (Prince, 2004).
3. Knowledge Management (128 mentions) and Task Management (123 mentions), though not directly part of the three metacognitive core functions, indirectly supported planning and monitoring by providing the necessary knowledge and skill foundation (Schraw & Dennison 1994).
4. Information Management (59 mentions) and Regulatory Strategies (42 mentions) further illustrated monitoring behaviors and strategy adjustments (Wood et al. 1976).

However, the Evaluation dimension (40 mentions) had the lowest frequency, suggesting that students exhibited relatively weaker metacognitive skills in self-assessment and reflection, possibly due to limitations in the implementation of reflective activities (Flavell 1979).

The analysis indicates that Phased Guidance (PG) and Timely Feedback (TF) were mentioned most frequently in students' reflections, suggesting their strong influence on learning outcomes (Vygotsky & Cole 1978).

1. Phased Guidance (PG), which structured the project into three stages—Proposal, Demonstration, and Final Report—strongly supported Knowledge Management (128 mentions) and Task Management (123 mentions). This approach helped students break down complex electrical design tasks into manageable components, providing clear objectives and structured steps (Puntambekar & Hübscher 2005). For example, students clarified circuit principles during the proposal phase and completed simulation validation in the demonstration phase, demonstrating PG's contribution to Planning (49 mentions) and Information Management (59 mentions) (Cukurova et al. 2018).
2. Timely Feedback (TF), delivered through real-time suggestions from instructors and peers, significantly enhanced Monitoring (87 mentions)

and Regulation (63 mentions) (Wood et al. 1976). After receiving feedback, students were able to adjust their designs and resolve issues promptly, aligning well with the debugging and optimization demands of the project (Hmelo-Silver et al. 2007).

1. In contrast, Reflective Activities (RA) had a lower impact on Evaluation (40 mentions). This may be due to students lacking sufficient metacognitive skills or the design of reflective tasks being less direct, leading to a slower emergence of its effects (Jonassen 2010).

The text analysis indicatesPhased Guidance (PG) and Timely Feedback (TF) had the greatest impact on students' metacognitive skill development in theMini Home Getaway Electrical Design projectKnowledge Management, Task Management, Monitoring, and Regulation (Prince, 2004). This highlights their directness and effectiveness in supporting metacognitive planning and monitoring functions (Guo et al. 2020).

1. PG reduced cognitive load by structuring task breakdown (Puntambekar & Hübscher, 2005),
2. TF enhanced students' self-regulation through real-time guidance (Wood et al. 1976).

In contrast, Reflective Activities (RA) had a weaker effect, with Evaluation being the least frequently mentioned dimension. This may be because reflection requires a higher level of metacognitive awareness, which some students had not yet fully developed, or because the 12-week project duration was insufficient to reveal its long-term effects (Kolmos et al. 2013).

The slightly positive sentiment in the sentiment analysis (Polarity = 0.074) further supports the overall effectiveness of scaffolding strategies (*(PDF) Natural Language Processing with Python*, n.d.). However, the relatively strong objectivity score (Subjectivity = 0.228) suggests that students were more focused on task execution rather than deep reflection (Cukurova et al. 2018).

DISCUSSION

OVERALL ENHANCEMENT OF METACOGNITIVE SKILLS

The primary objective of this study is to examine the effectiveness of Scaffolding Project-Based Learning (SPjBL) in cultivating metacognitive skills among engineering students. Based on peer-reviewed responses collected during the three-phase project (proposal, demonstration, and final report), it becomes evident that students demonstrated significant improvements in the three core metacognitive functions of planning, monitoring, and evaluation. This enhancement aligns with the central tenet of scaffolding theory, which posits that providing appropriate support within the learner's Zone of Proximal Development (ZPD) can gradually foster independent self-regulation (Vygotsky & Cole, 1978).

An analysis of students' reflective texts regarding the project process, informed by thematic and sentiment analysis, highlights the following:

1. Improved Planning Skills: Many students noted during reflections that Phased Guidance (PG) at the onset of the project "clarified the design direction" and helped them with "task breakdown" and "time management." As a result, when tackling multi-step circuit designs and resource allocation, they were able to set goals and delegate roles with greater confidence. This aligns with Puntambekar and Hübscher's view that systematically structured, phase-based task guidance effectively reduces cognitive load, allowing students to devote more energy to critical issues and planning (Puntambekar & Hübscher, 2005).
2. Maturation of Monitoring and Debugging Strategies: In later project stages (e.g., simulation demonstrations and physical prototype testing), the value of Timely Feedback (TF) became more pronounced. Students reported that when they encountered difficulties in TinkerCad or circuit board debugging, they could "promptly receive suggestions from instructors or peers," thereby continually refining their thinking and accumulating debugging experience. This immediate, dynamic feedback facilitated more frequent "self-monitoring," enabling them to regularly check progress, assess task feasibility, and make timely adjustments (Hmelo-Silver et al. 2007; Wood et al. 1976). Qualitative findings suggest that most students recognized this "point-to-point" feedback as having a positive impact on problem diagnosis and strategy optimization.
3. Potential for Growth in Evaluation and Reflection Skills: Although students frequently mentioned "identifying problems" and "optimizing solutions" during the project, their deep reflections at the evaluation level remained relatively weak. In interviews, some students frankly stated that while the specific steps involved in Reflective Activities (RA)—such as answering open-ended questions or writing periodic reports—were somewhat enlightening, they often felt

"constrained by limited time or experience," hindering deeper examination of their own learning processes (Flavell, 1979; Jonassen, 2010). This finding suggests that to significantly enhance students' evaluative skills in a short time, more targeted designs and guidance are necessary, such as providing more focused reflection prompts or hosting in-depth workshop-style discussions.

Based on these qualitative insights, several specific recommendations are proposed to enhance the design of future Reflective Activities (RA). First, RA prompts should be structured more explicitly and progressively, guiding students from basic descriptive reflections toward deeper analytical and critical evaluations of their learning processes. This structured guidance can encourage students to articulate clearly the rationale behind their actions and decisions, and subsequently evaluate their strategies and explore alternative solutions. Second, incorporating facilitated reflection workshops or peer discussion forums could provide social scaffolding, encouraging students to share diverse perspectives, thus enriching their reflective thinking. Additionally, introducing reflective journals or digital portfolios as longitudinal reflective tools would support sustained self-assessment and facilitate iterative refinement of students' metacognitive skills throughout the project phases. Finally, providing exemplars or models of high-quality reflective responses and embedding systematic instructor feedback could help clarify expectations, highlight effective reflection practices, and progressively guide students toward more sophisticated reflective abilities. These enhancements collectively aim to deepen students' reflective practice, thus strengthening their metacognitive regulation in engineering project contexts.

Overall, the positive influence of SPjBL on students' metacognitive skills is most apparent in the strengthened focus on "planning" and "monitoring." While its impact on the "evaluation" function is less direct, a certain potential is still evident. Students' written and verbal representations indicate that further stimulating higher-level self-evaluation and deeper reflection will require reinforced instructor guidance and more systematically organized reflection activities (Kolmos et al. 2013).

DIFFERENTIAL ROLES OF SCAFFOLDING STRATEGIES IN VARIOUS PHASES

1. Phased Guidance (PG)
   a. Early Phases (Proposal and Design): Particularly effective in reducing task complexity and providing a clear learning path. Students' reflections often mentioned that "phase checklists" or "template instructions" made them more confident when dealing with unfamiliar areas (e.g., sustainable design or different electronic components) and better able to coordinate group tasks (Pokharel, 2021).
   b. Later Phases (Finalization and Summary): Some students indicated that when scaffolding structures were overly detailed, they felt that their "freedom was limited," making it difficult to foster a higher level of self-direction and exploration (Puntambekar & Hübscher, 2005). This suggests that during the final stages of the project, it may be beneficial to reduce external guidance and encourage students to determine resource allocation and design strategies independently, thereby consolidating their self-regulatory abilities.

2. Timely Feedback (TF)
   a. Mid and Later Phases (Demonstration and Prototype Testing): Students expressed strong appreciation for TF in supporting "debugging and error correction" during hands-on practice and simulation validation. Given the real-time nature of circuit design and lab-based operations, peer reviews indicated that timely feedback not only minimized repetitive trial-and-error but also enhanced students' confidence in exploring alternative approaches (Hattie & Timperley, 2007).
   b. Close Coupling with Metacognitive Monitoring: After spontaneously recording and reporting mistakes or bottlenecks, students would use instructor or peer feedback for timely corrections, forming a "self-check → external suggestion → independent adjustment" cycle (Guo et al. 2020).

3. Reflective Activities (RA)
   a. Promoting Planning: Some students noted that regular reflective questionnaires or group discussions helped them "review issues from the previous phase," thereby clarifying next-step goals.
   b. Limitations for Evaluation Skills: Because new engineering students may be unfamiliar with reflective activities and time can be limited, some reflections remained superficial (e.g., "progress completion for the week" or "minor issues

encountered”), making it difficult to develop systematic self-evaluation (Flavell, 1979; Jonassen, 2010). To meaningfully enhance evaluation skills, RA designs must be optimized—for example, by providing more pointed questions, introducing peer assessments, or incorporating deeper investigative discussions.

Qualitative findings from this study reveal the differentiated contributions of these three scaffolding strategies to metacognitive skills at various project phases. In terms of pedagogical practice, instructors or instructional designers could flexibly adjust the intensity and format of scaffolding strategies according to the objectives of each phase and students’ feedback in order to maximize supportive effects (Prince, 2004).

IMPLICATIONS AND SIGNIFICANCE FOR ENGINEERING EDUCATION

In the context of Industry 5.0, engineering students not only require a solid foundation of disciplinary knowledge but also need self-regulation and reflective abilities to cope with rapid changes and high-intensity research or design projects (Lavado-Anguera et al. 2024). The insights from this study include:

1. Detailed Task Decomposition and Immediate Feedback Can Reduce Cognitive Load: Students repeatedly highlighted how Phased Guidance aided early learning and how Timely Feedback supported mid-to-late-stage debugging, reinforcing the idea that a “scaffolding + project-based” model can guide learners toward gradually developing metacognitive awareness in complex scenarios (Vygotsky & Cole, 1978).
2. Untapped Potential of Reflective Activities: Although students engaged in some degree of self-reflection, they did not generally conduct in-depth evaluations of their learning processes. Crafting more stimulating questions, encouraging multi-perspective analyses, and facilitating peer discussions may foster higher-level reflection (Schraw & Dennison, 1994).
3. Dynamically Adjusting the “Scaffolding Intensity”: For beginners, PG and TF should be more structured and frequent; however, as students gain more project experience, instructors can gradually step back, allowing learners greater autonomy and reinforcing their self-regulatory skills (Hattie & Timperley, 2007; Puntambekar & Hübscher, 2005).

In summary, by combining “structured guidance—immediate feedback—personal and peer reflection,” SPjBL provides a pedagogical model that holds both theoretical and practical significance for cultivating metacognitive competencies in engineering disciplines. Not only does it meet the need for professional knowledge transfer, but it also enables students to continuously reflect, monitor, and adjust their learning processes during project implementation, laying the groundwork for facing higher-level technical challenges in the future (Guo et al. 2020).

CONCLUSION

From a qualitative perspective, this study examines the genuine experiences and self-descriptions of students participating in the “Mini Home Getaway Electrical Design” project to evaluate the impact of Scaffolding Project-Based Learning (SPjBL) on improving metacognitive skills. Drawing on peer-reviewed answers and group submission data, the primary findings and conclusions can be summarized as follows:

1. Incremental Growth in Metacognitive Skills
    a. Students showed more significant gains in planning and monitoring, having gradually acquired circuit design and debugging strategies through external support such as PG and TF.
    b. Although students demonstrated some initial evaluation abilities, there remain limitations in conducting “in-depth reflection and systematic assessment,” indicating that more robust reflective designs are needed to deepen their examination of their own learning processes and outcomes (Flavell, 1979; Jonassen, 2010).

2. Complementary Effects of Scaffolding Strategies
    a. Phased Guidance (PG) was highly effective in clarifying learning objectives and breaking down tasks, thereby reducing cognitive overload for novices.
    b. Timely Feedback (TF) played a key role in dynamic monitoring and iterative design, guiding students in quick diagnostics and adjustments.
    c. Reflective Activities (RA) hold considerable potential for fostering self-evaluation and critical thinking over the long term, but require more systematic design and implementation (Kolmos et al. 2013).

3. Implications for Engineering Education Reform
    a. Introducing SPjBL into higher engineering education not only strengthens the contextualization and application of professional knowledge within project scenarios but also gradually cultivates students' independent learning and metacognitive regulation skills, laying a solid foundation for tackling complex engineering tasks (Prince, 2004). By appropriately integrating PG, TF, and RA at different stages, instructors can develop a flexible and adaptive scaffolding system that enhances students' awareness and control of their own learning processes (Hattie & Timperley 2007)

In conclusion, this study—within a purely qualitative framework—investigates how SPjBL can deepen students' metacognitive skills in project-based learning contexts. The findings resonate with scaffolding theory and offer practical, actionable strategies for educators in the field of engineering. Future research on the specific design of reflective activities, extended project timelines, and different learner needs may further refine the SPjBL model (Guo et al. 2020), strengthening its capacity to meet the challenges of engineering education reform in the Industry 5.0 era (Lavado-Anguera et al. 2024; Prince 2004; Vygotsky & Cole 1978).

Additionally, it is important to acknowledge that this study was conducted within a specific educational and cultural context—first-year electrical engineering students at a Malaysian university. The unique characteristics of this population, including their initial stage of technical and metacognitive skill development, as well as the pedagogical and cultural norms specific to Malaysian higher education, may limit the direct generalizability of these findings to other contexts or disciplines. Consequently, caution should be exercised when extending these results beyond similar populations or educational settings. Future studies should involve broader participant groups across diverse educational contexts and cultural backgrounds to verify and extend the applicability and effectiveness of the SPjBL approach.

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DECLARATION OF COMPETING INTEREST

None.

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