The Impact of Scaffolding on the Development of Metacognitive Skills in Project-Based Engineering Learning

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Abstract

This research explores the impact of scaffolding in Project-Based Learning (PjBL) on the development of students' metacognitive skills. Metacognitive skills are crucial in engineering courses as they enable students to navigate complex tasks by self-monitoring and adjusting strategies. The research designed a multi-layered scaffolding approach incorporating structured tasks, staged feedback, reflective prompts, and group discussions to support learning and reflection in a "Cultural and Technological Food Cart Design Challenge." Based on Vygotsky's Zone of Proximal Development (ZPD) and constructivist theories, the scaffolding provided guidance at various learning stages, progressively enhancing students' understanding, monitoring, and information management skills. Using a mixed-method approach, quantitative data were collected through the Metacognitive Awareness Inventory (MAI) to track metacognitive progress, while qualitative data from daily reflection logs captured students' experiences. Results showed significant improvements in metacognitive skills in comprehension monitoring and information management ($p < 0.05$), though limited project duration restricted the development of planning and self-evaluation skills. The research offers optimization insights for scaffolding in PjBL, particularly highlighting the positive effects of scaffolding on emotional regulation and self-motivation in cross-cultural projects, providing a reference for future pedagogical practices in complex tasks.

Keywords: Project-Based Learning (PjBL), scaffolding, metacognitive skills, engineering project, cultural and technology design.

Introduction

Background and Problem

In modern engineering project courses, cultivating students' metacognitive skills is crucial (Jumaat et al., 2017). Metacognition refers to students' ability to recognize and regulate their learning processes, which directly impacts their performance in complex projects. Students with strong metacognitive skills are not only able to effectively handle uncertainties within projects but also continuously improve their performance and learning outcomes through self-assessment and strategy adjustments during task execution. In recent years, Project-Based Learning (PjBL) has gained widespread attention as a practice-oriented teaching approach (Admawati et al., 2018; Pokharel, 2021). Through the simulation of real-world tasks, PjBL helps students apply theoretical knowledge within projects, fostering critical thinking and problem-solving abilities. Compared to traditional exam-focused teaching models, PjBL is better suited for developing the core skills required of modern engineers, such as lifelong learning, decision-making, and teamwork.

In this context, Vygotsky's theory of the Zone of Proximal Development (ZPD) and constructivist theory provide theoretical support for scaffolding techniques in PjBL (Rahayu et al., 2022). ZPD theory posits that students achieve optimal learning outcomes within the "zone of proximal development," where, with appropriate support, they can accomplish tasks they would otherwise be unable to complete independently. In PjBL, scaffolding serves precisely this role by providing essential support that gradually leads students to achieve higher levels of task

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accomplishment. Constructivist theory, on the other hand, emphasizes that knowledge is constructed through active participation and accumulated experience (Jumaat et al., 2017). PjBL, through real task implementation and reflection, offers an environment that enables students to construct knowledge autonomously and continuously enhance their learning.

Traditional engineering project courses often focus on knowledge transmission, with assessments used to gauge students' mastery of the material. In PjBL, however, students engage in actual projects, solve real-world problems, and progressively build a structured knowledge base and skill set. The core of PjBL is to encourage students to learn and explore actively through realistic project tasks (Admawati et al., 2018; Blumenfeld et al., 1991). Nevertheless, the effectiveness of PjBL largely depends on the appropriate application of scaffolding support. Scaffolding, through structured guidance and staged feedback during the learning process, helps students achieve project goals incrementally, thereby effectively enhancing their self-management and regulatory abilities (Pokharel, 2021).

This research integrates reflective prompts and guided feedback, rooted in Vygotsky's ZPD theory and the cultural diversity of task design (Vygotsky & Cole, 1978). Unlike the scaffolding approaches described by Blumenfeld et al. (1991), which are predominantly applied in single-discipline projects, this research incorporates a multi-layered task breakdown and staged feedback within a cross-cultural context (Blumenfeld et al., 1991). This design not only enhances students' task management and reflective skills but also fosters their cultural adaptability and collaboration (Jumaat et al., 2017).

Significance of the research

The core function of scaffolding in PjBL lies in providing students with phased support and feedback, giving them clear guidance at each project stage, and encouraging timely reflection and adjustments. Existing research suggests that scaffolding plays a vital role in enhancing metacognitive skills (Jumaat et al., 2017; Pokharel, 2021). First, scaffolded support helps students effectively monitor their learning progress, integrate information, and apply knowledge to manage complex tasks (Admawati et al., 2018; Blumenfeld et al., 1991). Additionally, the staged feedback mechanism in scaffolding encourages students to reflect on and modify their learning strategies, fostering a sense of self-regulation, which is especially critical in engineering projects (Rahayu et al., 2022). For instance, scaffolding can help students quickly adjust strategies when encountering challenges, ensuring that the project progresses as planned.

In engineering project courses, cultivating metacognitive skills generally encompasses various aspects, such as task comprehension and monitoring, information management, learning plan adjustments, and self-reflection. Based on Vygotsky's ZPD theory, scaffolded support gradually reduces external assistance, guiding students to transition from relying on scaffolds to independently completing tasks, thereby continuously expanding their cognitive and knowledge application capabilities (Jumaat et al., 2017; Pokharel, 2021). Constructivist theory, in turn, highlights that through hands-on practice and autonomous exploration, students in PjBL not only acquire knowledge but also develop critical thinking and independent problem-solving skills (Admawati et al., 2018).

Building on existing PjBL frameworks, this research enhances students' metacognitive skills in complex tasks by employing a multi-layered scaffolding strategy. It incorporates a systematic support mechanism that includes structured tasks, staged feedback, reflective prompts, and group discussions, tailored to the needs of different learning stages, and helping students improve their comprehension monitoring and information management skills (Blumenfeld et al., 1991). Additionally, this research's "Cultural and Technological Food Cart Design Challenge" project introduces a real-world application scenario with cross-cultural elements, allowing students to gain in-depth experiences of diverse cultures through PjBL. This design enhances the realism and engagement of the project, helping students develop skills in information integration and adaptability across various cultural settings.

This research also adopts a mixed-method approach, combining quantitative analysis using the Metacognitive Awareness Inventory (MAI) with qualitative data from daily reflection logs, providing a multi-dimensional evaluation of scaffolding effectiveness, and ensuring empirical validity of the results (Pokharel, 2021; Rahayu et al., 2022).

Through a project-based design and multi-level support system, this research offers practical insights for optimizing scaffolding techniques in PjBL, particularly by providing innovative educational recommendations for diverse feedback and promoting self-regulation. These findings not only offer direction for improving teaching practices in engineering project courses but also lay a solid theoretical and practical foundation for future applications of scaffolding in cross-cultural and complex task environments.

Research Objectives

The primary aim of this research is to investigate how the integration of scaffolding techniques in PjBL engineering project courses can enhance students' metacognitive skills. Figure 1 illustrates the objectives are as follows:

1. *Evaluate the impact of scaffolding on students' comprehension monitoring, information management, and planning skills:* This objective

involves analyzing how scaffolding assists students in better understanding project requirements and enhancing efficiency in information processing and task management (Hobri, 2021). By providing clear task descriptions and goal breakdowns at the start of the project, scaffolding aims to establish a comprehensive understanding of the task, thereby facilitating subsequent information integration and application.

2. *Examine the long-term effects of structured support on students' self-regulation and reflective abilities:* This objective evaluates how scaffolding aids students in gradually developing reflective and self-regulatory skills during the project execution phase, thereby supporting future learning and improvement in similar projects (Jumaat et al., 2017).
3. *Provide optimized recommendations for applying scaffolding in engineering project courses* (Jalinus et al., 2023)*:* Based on the research's findings, this objective aims to offer practical methods for implementing scaffolding in engineering project-based courses to effectively develop students' metacognitive skills. For instance, by incorporating staged feedback mechanisms and designing reflective tasks, scaffolding can be optimized to help students enhance self-management and regulatory capabilities.

This research employs a mixed-methods approach, systematically evaluating the effectiveness of scaffolded support in PjBL tasks. Figure 1 illustrates the theoretical framework underlying this research, which integrates the principles of scaffolding and Project-Based Learning (PjBL) to develop students' metacognitive skills (Jumaat et al., 2017). The findings will provide theoretical and practical guidance for designing and implementing scaffolding in engineering project courses, thus enhancing students' metacognitive development and self-regulation in future educational practices (Blumenfeld et al., 1991).

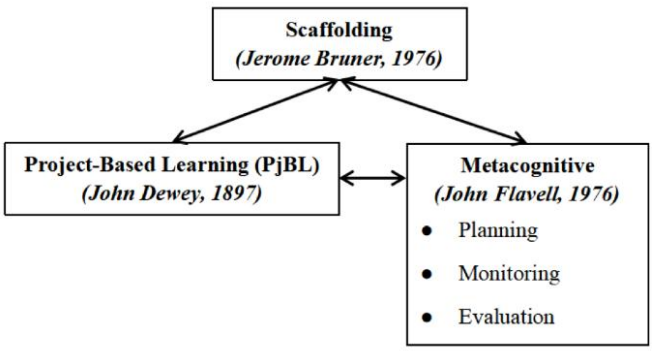

Figure 1. Theoretical Framework

Research Methodology

Research Design

This research adopts a mixed-methods research design, combining quantitative and qualitative analyses to evaluate the impact of scaffolded support on the metacognitive skills of students (Rahman et al., 2022). Participants engaged in a seven-day "Cultural Innovation Journey" project, with the central task being the "Cultural and Technological Food Cart Design Challenge."

The research involved 25 undergraduate students from diverse academic backgrounds. Although the gender distribution was uneven, efforts were made to balance the groups by ensuring similar gender ratios within each team. Teams were organized based on personality types (e.g., introversion/extroversion, determined by the MBTI test) and learning styles (e.g., visual, auditory, reading/writing, kinesthetic, based on the VARK questionnaire) to foster diversity and collaboration within each group (Rahman et al., 2022). This grouping strategy included a range of introversion/extroversion traits and multiple learning styles to maximize complementary skills among team members, maintain team dynamic balance, minimize external influences on scaffolding support outcomes, and provide a foundation for subsequent data analysis.

Figure 2 illustrates the scaffolding techniques were integrated into this multi-stages, cross-cultural project task to assess their effectiveness in enhancing metacognitive skills, such as comprehension monitoring, planning, and self-reflection (Pokharel, 2021). This theoretical framework is largely based on the Zone of Proximal Development (ZPD) introduced by Lev Vygotsky in 1978, which emphasizes that learning occurs most effectively within a 'zone' where students can achieve tasks with appropriate guidance that they could not accomplish independently. Additionally, constructivist theory, as outlined by Piaget, highlights the role of active participation and experience accumulation in knowledge construction (Blumenfeld et al., 1991; Vygotsky & Cole, 1978).

Scaffolding Support Design

In alignment with scaffolding theory, this research integrated the following scaffolding support measures in the PjBL activities to enhance students' metacognitive regulation (Hobri, 2021):

1. *Structured Steps:* The main project task was divided into multiple subtasks, each with clear goals and steps. For example, on the first day, students were tasked with observing cultural landmarks, examining architectural elements, cultural symbols, and culinary choices (Jalinus et al., 2023). This structured steps design focused students' attention on fundamental elements, fostering their development of design thinking.

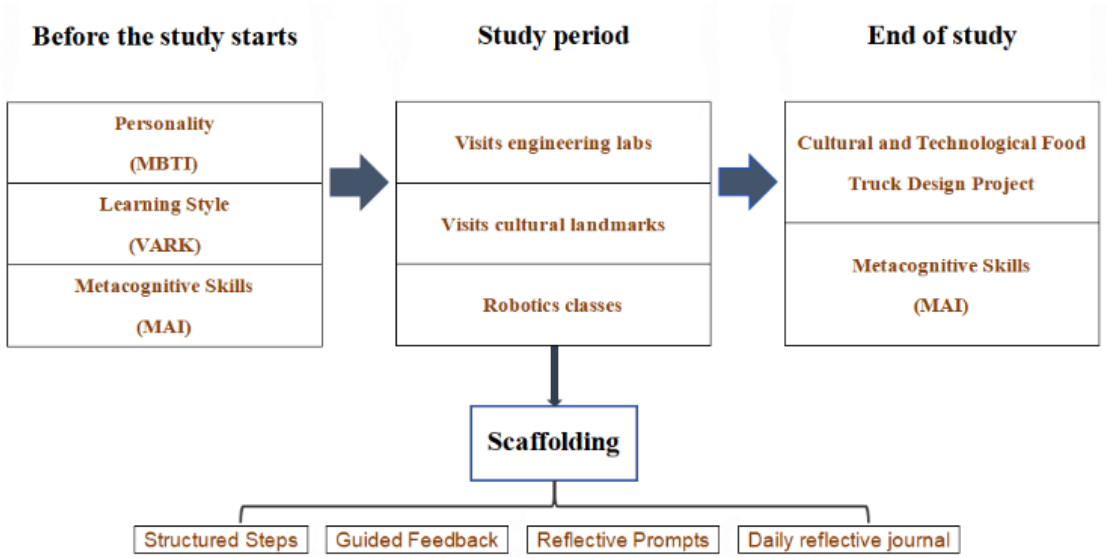

Figure 2. Project Framework

2. *Guided Feedback:* Feedback was provided at critical points based on project stages. At the end of each day, students received feedback on their observations and thought processes, particularly with reflective prompts on the second day and design reports on the third day (Blumenfeld et al., 1991). This feedback helped students reflect on their progress and adjust strategies to complete their tasks effectively.
3. *Reflective Prompts:* Daily reflective tasks were assigned to encourage students to document their design thinking processes, thereby promoting metacognitive skill development. Reflection logs included main observations, design inspirations, challenges encountered, and solutions attempted each day, enabling students to review and adjust their learning strategies throughout the process.
4. *Group Discussions (daily reflective journal and truck design project):* Each project phase incorporated group discussions and reporting tasks, where team members shared diverse perspectives to enrich understanding and improve design plans. Group discussions provided an interactive platform where students could gain insights from peers' feedback, further expanding their design thinking.

The task breakdown followed a multi-phase approach. For example, on the first day, students were assigned to observe cultural landmarks and extract architectural and cultural symbols; on the second day, they recorded their observations in reflective journals and shared their findings with team members (Pokharel, 2021). This step-by-step approach helped students decompose complex tasks and integrate cultural elements into their designs. Staged feedback was implemented through daily instructor reviews and group discussions, enabling students to adjust their learning strategies. For instance, one student shifted from 'simply imitating cultural symbols' to 'integrating multiple cultural elements into the design' following feedback.

Data Collection and Analysis

Multiple data collection methods were employed to ensure comprehensive and reliable results:

1. *Quantitative Data:* The Metacognitive Awareness Inventory (MAI) was used to assess students' metacognitive skills before and after the project. The MAI evaluates metacognitive abilities across four dimensions: comprehension monitoring, information management strategies, planning, and evaluation (Andari et al., 2020). A paired-sample t-test was applied to analyze changes in MAI scores pre- and post-project, assessing the effectiveness of scaffolding support.
2. *Qualitative Data:* Daily reflection logs and group feedback captured students' in-depth experiences related to task comprehension, strategy adjustments, and changes in metacognition. Coding and thematic analysis were conducted on qualitative data to identify behavioral changes in learning under various scaffolding support conditions and to explore metacognitive behaviors across different project stages (Rahayu et al., 2022).

Data Analysis Methods:

1. *Paired-Sample t-Test:* This test was conducted to analyze pre- and post-test MAI scores, verifying the statistical significance of scaffolding support in enhancing metacognitive skills (Rahayu et al., 2022).
2. *Thematic Analysis:* Qualitative analysis software (e.g., NVivo) was used to conduct thematic analysis on the reflection logs, focusing on students' expressions related to comprehension monitoring, planning adjustments, and reflective

evaluation (Pokharel, 2021). This helped to identify specific effects of scaffolding support.

3. *Correlation Analysis:* Relationships between different dimensions of metacognitive abilities in the quantitative data were examined, exploring interactions among comprehension monitoring, planning, and evaluation influenced by scaffolding techniques (Jumaat et al., 2017).

This research design ensures that quantitative and qualitative data complement each other, providing a multidimensional understanding of scaffolding support's role in enhancing metacognitive skills within PjBL tasks. By integrating quantitative and qualitative data, this research aims to capture the complex effects of scaffolding on metacognitive skills and offer empirical insights for optimizing scaffolding design in engineering projects.

Results

Quantitative Results

Table 1 tabulates the quantitative results from the MAI assessment, summarizing the changes in students' metacognitive skills across various dimensions before and after the project (Andari et al., 2020; Pokharel, 2021). It highlights significant improvements in comprehension monitoring and information management strategies. It demonstrates a significant improvement in students' metacognitive skills related to comprehension monitoring and information management strategies ($p < 0.05$), indicating that scaffolding support has a direct positive impact on students' reflective and information-processing abilities within project tasks (Andari et al., 2020). However, no significant improvement was observed in planning and self-evaluation ($p > 0.05$) (Čavić et al., 2023). Detailed quantitative analyses are as follows:

- *Significant Improvement in Comprehension Monitoring:* The average score for comprehension monitoring increased from 3.96 (pre-test) to 4.92 (post-test), reflecting an enhanced ability to reflect and understand the project process ($p = 0.015$) (Wengrowicz et al., 2018). For example, on day five, student A observed the layout of cultural landmarks and, with feedback from the instructor, was able to integrate her observations into her design by day seven. This suggests that with scaffolding support, students could more effectively monitor and adjust their learning strategies.
- *Improvement in Information Management Strategies:* Students' average score in information management strategies rose from 7.20 to 7.92 ($p = 0.031$), indicating an increased capacity to integrate and manage multiple sources of information (Marra et al., 2022). Specific feedback examples include student B, who noted the transition from observing colorful architecture to designing a food cart incorporating natural elements. This highlights their improved ability to synthesize and apply information in a cross-cultural project setting.
- No Significant Improvement in Planning and Self-Evaluation: No significant changes were observed in students' scores for planning and self-evaluation ($p > 0.05$), which may be attributed to the short project duration, as it limited opportunities for deep reflection and self-regulation (Sart, 2014). Some students reported that the project's time constraints and task demands made it challenging to engage in systematic planning and comprehensive reflection. For instance, student C noted that, within the limited timeframe, she could only perform basic reflection without the opportunity to delve into higher-level planning and self-evaluation strategies (Marra et al., 2022). The limited improvement in planning and self-evaluation skills can be attributed to the short duration of the project (Kazanjian, 2023). Several students noted in their reflective journals that, due to time constraints, they prioritized task completion over comprehensive project planning. For example, Student C stated, 'Despite the feedback, I primarily focused on the immediate tasks rather than engaging in detailed planning.' This indicates that short-term projects may not provide sufficient practice opportunities for the development of advanced metacognitive skills.

Table 1. Results for Metacognitive Skills

Metacognitive Skill	Pre-Test Mean	Post-Test Mean	p-value
Declarative Knowledge	5.24	5.48	0.282
Procedural Knowledge	2.68	2.92	0.341
Conditional Knowledge	3.80	3.68	0.612
Planning	4.48	4.64	0.527
Comprehension Monitoring	3.96	4.92	0.015*
Information Management Strategies	7.20	7.92	0.031*
Debugging Strategies	4.28	4.32	0.852
Evaluation	4.20	4.32	0.588

Qualitative Results

Table 2 demonstrates the thematic analysis of students' daily reflection journals and feedback. This research found that scaffolding support gradually enhanced students' task comprehension, information management, and flexibility in problem-solving strategies (Andari et al., 2020). Figure 3 shows students' feedback where all participants agreed that the PjBL experience not only broadened their perspectives and deepened their understanding of unique local cultures but also exposed them to a diversity of cultural influences (Rahayu et al., 2022). This exposure fostered growth in self-awareness and critical thinking, encouraging students to reflect on their beliefs and strategies (Aufa et al., 2021). As they engaged with different cultures, students improved their adaptability and collaborative skills, and these skills ultimately enriched their learning experiences with greater meaning.

Table 2. Students' Daily Reflection Journals and Feedback

Theme	Main Content	Reflected Metacognitive Skill	Feedback Reporting from Scaffolding Support
Task Completion	Students' descriptions of task completion, such as visiting cultural landmarks and observing booth layouts.	Planning and Execution Management	Clear task objectives make it easier for students to complete tasks. Staged task checklists and goal-setting aid in their self-management during execution.
Observation and Experience	Observations of culture, architecture, and other aspects, such as the design of mosques, booth layout, and decorations at landmarks like the Petronas Towers.	Comprehension Monitoring	Providing observation prompts and cultural background helps students gather more detailed insights, integrating cultural elements into design effectively. Reflective prompts help them gradually adjust design direction.
Design Insight or Inspiration	Inspiration for designs, such as combining religious elements of mosques with modern architectural styles or incorporating Malaysia's multicultural aspects.	Information Management Strategies	Reflection logs and staged feedback help students clarify design ideas and adjust plans flexibly. Students gradually refine their design direction, with inspirations closely linked to scaffolding support.
Challenges and Solutions	Challenges encountered and coping methods, such as spatial layout constraints, merging multicultural elements, and selecting materials.	Problem-Solving and Planning Ability	Regular feedback and group discussions provide support in tackling challenges. Students report that feedback and discussions enhance confidence and effectiveness in finding viable solutions.
Reflection and Feedback	Students' reflections on scaffolding support, particularly on reflection logs and feedback.	Self-Evaluation and Reflection Ability	Students find that reflection logs assist in reviewing and summarizing task progress, gradually improving design thinking and problem-solving skills. This support fosters metacognitive skill development, especially in evaluation and self-reflection.
Emotion and Attitude Evolution	Students' emotional shifts throughout the project, from initial tension and confusion to eventual confidence and a sense of achievement.	Emotion Regulation and Self-Motivation	Task breakdown and feedback support help students maintain a positive attitude through challenges and achieve a sense of accomplishment upon task completion.
Time Series Analysis	Trends in metacognitive skill development over the course of the project, such as from superficial observation to deep analysis and from simple imitation to proactive innovation.	Overall Metacognitive Skill Development	Continuous feedback and regular goal-checking support gradual improvement in students' metacognitive skills, enhancing their reflection and innovation abilities throughout the project.

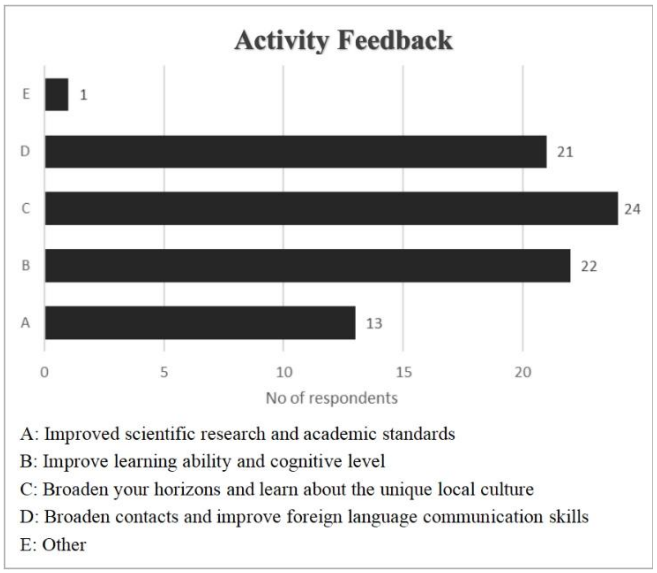

Figure 3. Students' Feedback

This combination of learning and reflection led to growth in adaptability, collaboration, and other key competencies, which further reinforced their metacognitive skills and positively impacted their problem-solving and innovative thinking abilities (Jumaat et al., 2017). Feedback suggests that scaffolding support helped students more fully understand and apply learned concepts, enhancing both cultural understanding and information integration skills, which are critical metacognitive skills needed to address complex problems.

The following summarizes the improvements in metacognitive skills facilitated by scaffolding support, alongside specific examples from student reflections:

- *Comprehension Monitoring:* Staged task feedback significantly enhanced students' comprehension monitoring, helping them clarify objectives and adjust strategies throughout the project. For instance, student D reported that the feedback from scaffolding allowed her to pinpoint her current task at each stage and make gradual adjustments to her design plan.
- *Information Management Strategies:* Students progressively learned to integrate multi-sourced information from diverse cultural contexts and incorporate this information into their designs. For example, student E noted on day six that the modern architectural style of the Petronas Towers inspired his design, leading him to effectively integrate various cultural elements in his subsequent work. This shows how scaffolding support guided students from observation to application, fostering the development of their information management skills.
- *Challenges and Solutions:* Students encountered challenges in design tasks, often related to integrating diverse cultural elements, spatial arrangements, and material selection. The scaffolding feedback and group discussions provided crucial problem-solving support. For instance, student F faced difficulties in merging modern and traditional elements. Through group discussions, he gained inspiration and successfully incorporated Southeast Asian cultural and modern technological elements in his design on day seven.
- *Self-Evaluation and Reflection:* Reflection logs encouraged students to review task progress and design ideas daily, gradually strengthening their self-evaluation and reflection abilities. Student G shared that the staged logs helped her better summarize task progress and adjust her design plan promptly, improving her self-evaluation skills.

These insights illustrate how scaffolding in PjBL fosters metacognitive growth, enabling students to refine their approaches to learning, problem-solving, and creative thinking in complex engineering tasks

Impact of the Project on Emotional Regulation and Self-Motivation

Through thematic analysis of students' daily reflection logs, the research found that scaffolding support played a significant role in helping students regulate emotions and enhance self-motivation, contributing positively to their learning experiences.

- *Emotional Regulation:* Early in the project, some students reported feeling nervous and confused due to unfamiliarity with the task content. However, as the project progressed, the scaffolding support—such as task breakdown, reflection logs, and feedback mechanisms—helped students maintain a positive attitude when facing challenges and gradually build confidence (Hobri, 2021). For example, student A noted that with phased feedback, she gradually overcame her initial anxiety and became more confident in tackling project challenges.
- *Self-Motivation:* By completing tasks and receiving instructor feedback, students generally felt a sense of accomplishment by the end of the project, recognizing their progress in design thinking and cultural understanding (Jumaat et al., 2017). Student H expressed appreciation for the project experience in her reflection on the seventh day, saying, *"I am very grateful to all the teachers for their hard work along the way."* This feedback illustrates that the scaffolding support not only boosted students' self-motivation but also enhanced their sense of achievement.

Time Series Analysis: Evolution of Metacognitive Skills

A time series analysis of metacognitive skill development during the project reveals how students gradually advanced to more profound levels of

reflection and innovation under the guidance of scaffolding support (Jumaat et al., 2017).

- *From Surface Observation to In-Depth Analysis:* At the beginning of the project, students tended to focus on surface-level observations, but with scaffolding support, they gradually developed deeper analytical skills (Pokharel, 2021; Rahayu et al., 2022). For instance, student D initially concentrated on the decorative elements of the food truck on the fifth day, but by the seventh day, her focus had shifted to considering the environmental sustainability of materials and cultural adaptability, illustrating her progress in the project.
- *From Simple Imitation to Proactive Innovation:* Early on, students relied heavily on imitation in their designs; however, with iterative feedback, they transitioned to autonomous innovation (Andari et al., 2020). For example, the student I mentioned difficulties in integrating local cultural elements with design concepts at the start of the project but by the seventh day, she proposed a unique design combining cultural elements with modern aesthetics. This shift demonstrates how scaffolding helped students' progress from mere imitation to original creative expression (Jalinus et al., 2023).

Discussion

Interpretation of Results

The quantitative analysis in this research indicates that scaffolding support led to significant improvements in students' comprehension monitoring and information management strategies. This suggests that structured tasks and staged feedback provided students with clear learning pathways and specific goals, enhancing their ability to monitor and manage information throughout the task (Malik et al., 2023). Such improvements may result from the targeted guidance and timely feedback offered through scaffolding, which helps students focus on their objectives and gradually develop strategies for integrating and applying information. However, no significant improvements were observed in students' planning and self-evaluation skills in the short term. This may be because advanced metacognitive skills, such as planning and self-evaluation, generally require extended periods of practice to fully develop. Additionally, the limited project duration and task pressure may have restricted students' opportunities for reflection and self-evaluation. These findings suggest that fostering these higher-level metacognitive skills may require ongoing support beyond a single project to cultivate complex self-regulation abilities (Jumaat et al., 2017).

Integration of Qualitative and Quantitative Data

The integration of qualitative data further clarifies the differences observed in skill improvements in the quantitative results (Andari et al., 2020). Qualitative cases illustrate that scaffolding support helped some students gradually improve their task comprehension and flexibility in information management. For example, during the project, some students began incorporating observations into their design, demonstrating how task breakdowns facilitated her comprehension monitoring (Hobri, 2021). In contrast, feedback from some students indicated that the pressure of the short-term project impeded their ability to fully engage in self-evaluation and planning, corroborating the quantitative findings of no significant improvement in these skills. Future studies could explore more flexible timelines and additional reflection opportunities to determine if these adjustments influence results, thereby strengthening scaffolding support for metacognitive skill development.

Differences in Personality Types and Learning Styles

If data permits, future studies could analyze differences among students with various personality types (e.g., based on MBTI) and learning styles (e.g., VARK preferences) to better understand the impact of scaffolding on different student groups (Rahman et al., 2022). For instance, extroverted students may benefit more quickly from group discussions and interactions, while introverted students may require more structured tasks and individualized feedback to enhance information management and planning skills (Hobri, 2021). Exploring these individualized differences could help educators tailor scaffolding more precisely to maximize its effectiveness for diverse student groups (Rahayu et al., 2022).

Comparison with Existing Research

The findings of this research align with existing literature. Consistent with the results of Blumenfeld et al., scaffolding in PjBL significantly improved students' comprehension monitoring and information management skills (Blumenfeld et al., 1991). However, Blumenfeld et al. also emphasized the need for sustained and adaptive scaffolding, which this research supports by showing that certain metacognitive skills require long-term support and repeated reflection (Jumaat et al., 2017). In this short-term project, students showed no significant progress in planning and self-evaluation, indicating the need for dynamic scaffolding adjustments to support long-term skill development.

Limitations and Future Research Directions

While scaffolding in PjBL environments has shown positive effects in fostering students' metacognitive

skills, certain limitations exist. The following areas, including sample size and project duration, dynamic feedback mechanisms, diversity of scaffolding types, cross-cultural adaptability, and practical applications, are discussed to provide a broader reference for future research and teaching (Kazanjian, 2023).

1. *Sample Size and Project Duration:* This research was conducted with a small sample size and over a relatively short project cycle, meaning that the findings may not fully reflect the long-term impact of scaffolding on metacognitive skill development. Future studies could consider expanding the sample size and extending the project duration to verify the enduring effects of scaffolding (Rahayu et al., 2022). A longer cycle would allow a more comprehensive capture of students' continuous progress in comprehension monitoring, information management, and self-evaluation, further supporting educators in selecting and applying scaffolding strategies with greater precision in instructional design (Pokharel, 2021).
2. *Dynamic Feedback Mechanism:* The current scaffolding design is primarily based on pre-set task structures and feedback methods, which, while promoting metacognitive skills to some extent, still lack flexibility and personalization. Future research could explore dynamic feedback mechanisms, such as AI-based adaptive feedback tools, that provide real-time guidance based on students' progress and performance (Jalinus et al., 2023). This type of feedback mechanism could more closely align with students' actual needs, offering immediate support when challenges arise, thus enhancing the application of complex skills like task planning and self-evaluation (Aufa et al., 2021).
3. *Effectiveness of Different Scaffolding Types:* Different types of scaffolding may have varying impacts on different aspects of metacognitive skills. For example, structured tasks may be more effective in improving students' comprehension monitoring, while reflective journals may be better suited for developing self-evaluation skills (Andari et al., 2020). Future research could further explore the optimized effects of combining various scaffolding types on different metacognitive skills. Through flexible application of multiple scaffolding combinations in course design, educators could more effectively support students in developing self-management and self-regulation skills (Jumaat et al., 2017).
4. *Cross-Cultural Adaptability:* With the globalization of education, the potential for applying scaffolding in PjBL projects within cross-cultural contexts has become increasingly evident. The results of this research suggest that scaffolding can help students better integrate and apply knowledge in diverse cultural environments (Malik et al., 2023). Future research could focus more on the applicability of scaffolding in different cultural contexts, exploring how scaffolding might support students in deepening their understanding of cultural differences and effectively incorporating multicultural elements (Ismail et al., 2024). Educators could design cross-cultural collaborative projects to encourage students to work in diverse teams, enhancing their cultural adaptability and flexibility in addressing complex problems (Wati et al., 2024).
5. *Practical Implications:* The practical application of scaffolding in engineering projects demonstrates valuable outcomes. By systematically integrating scaffolding techniques into course design, educators can adopt a "task breakdown-feedback-reflection" model to help students progressively adapt to complex project tasks, clarify task objectives, and develop gradual self-management and regulation skills (Admawati et al., 2018). Additionally, the use of scaffolding in cross-cultural project learning has shown to be effective; through incorporating cultural experiences and teamwork within project tasks, students can enhance their collaborative skills while understanding diverse cultures (Andari et al., 2020). This approach not only aids students in acquiring knowledge and skills but also strengthens their metacognitive development and cross-cultural adaptability, providing broader support for students in future work and learning environments (Ghazali et al., 2019; Rahayu et al., 2022).

In summary, this research provides empirical support for the effectiveness of scaffolding in enhancing students' metacognitive skills within PjBL. Future research should continue to optimize design aspects such as sample size, feedback mechanisms, types of scaffolding, and cultural adaptability to further improve the effectiveness of scaffolding in engineering project (Pokharel, 2021).

This research demonstrated the significant impact of reflective prompts and guided feedback in short-term projects, particularly in enhancing students' comprehension monitoring and information management skills. However, it also highlighted the limitations of short-term projects in fostering advanced metacognitive skills. By proposing strategies such as extending project duration and optimizing feedback mechanisms, this study provides new insights into the application of scaffolding techniques in complex engineering projects (Pokharel, 2021).

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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