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WIP: Prompt-led Learning Model for First-year Education: a Metacognition Learning Pathway

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Introduction

First-year engineering courses play an important role in shaping how students approach problem solving, build knowledge, and understand their own learning processes. While these courses introduce technical foundations, they also influence how students define problems, evaluate evidence, and manage uncertainty. Research shows that many beginners focus on completing tasks rather than understanding the reasoning behind their solutions, often producing working designs without fully grasping underlying concepts [1], [2]. At the same time, artificial intelligence tools—particularly language-based systems—are becoming more common in engineering classrooms and, when used intentionally, can support learning by prompting students to explain ideas, question assumptions, and refine their thinking. This supports the development of metacognition, or the ability to reflect on and regulate one's own thinking, which is linked to persistence and success in STEM but is rarely taught explicitly in early courses [6]–[9]. Project-based learning offers opportunities for such reflection, yet without structured guidance students often focus on completing tasks rather than examining their reasoning, resulting in project reports that document actions rather than learning [10], [11].

Recent engineering education research emphasizes integrating reflection directly into project workflows rather than treating it as a final add-on [12], [13]. One effective approach is structured prompting, where carefully designed questions guide students to explain decisions, examine evidence, and consider alternatives throughout a project. Studies across STEM fields show that iterative prompts improve conceptual understanding and technical communication when used consistently during the learning process [14], [15]. Advances in AI language models now enable this support to be delivered more interactively, creating dialogue that encourages students to articulate and refine their thinking step by step [4], [16], [17]. Importantly, research suggests the value of AI in education lies not in generating answers but in helping students organize how they think, which is an approach that may be especially helpful in early project stages when first-year students struggle to transform broad ideas into clear, testable engineering problems [18], [19].

This paper explores how a prompt-led, AI-supported approach within a Vertically Integrated Project (VIP) course can help first-year engineering students develop stronger reflective skills, clearer reasoning, and more thoughtful project ideas. Research suggests that novice designers benefit from structured guidance that helps them articulate problems, consider constraints, and evaluate feasibility [20]. Prompts focused on data needs, validation strategies, and ethical considerations can support this transition while strengthening metacognitive awareness and planning skills. The central research question guiding this work: **How do students engage with AI-supported prompts embedded in engineering assignments, and what evidence suggests that these prompts support reflective reasoning and communication?** By examining changes in metacognitive awareness, analytical writing quality, and creative ideation, this study responds to recent calls from the engineering education community to rigorously evaluate instructional innovations that leverage AI while maintaining a strong theoretical grounding [3], [12], [21].

Method

This study employed a quasi-experimental, mixed-methods research design to examine how a prompt-led learning framework influences first-year STEM students' metacognitive awareness, scientific communication, and creative problem-solving. The intervention was implemented within a first-year undergraduate engineering course that emphasized project-based learning as a central pedagogical approach. The course required students to work in teams on an open-ended design project that involved problem identification, hypothesis development, experimental reasoning, and written technical reporting. The instructional context provided an authentic environment in which metacognitive processes could be observed as students navigated complex and ill-structured tasks.

15 Participants were enrolled in the course called Vertically-Integrated Projects (VIP). The students experienced the prompt-led learning framework, in which structured reflective prompts were embedded throughout project ideation, experimentation, and reporting. Group assignment followed existing course enrollment structures, resulting in a quasi-experimental design rather than random assignment. All participants had similar academic backgrounds and limited prior formal exposure to metacognitive training.

Structured prompts were embedded directly into three graded assignments during the first half of the semester rather than used as standalone reflections. During the project proposal stage, students interacted with prompts such as "What assumptions underlie your problem statement?" and "What data would demonstrate feasibility?" and included a brief reflection describing how their idea evolved. During the experimental design phase, prompts such as "What outcomes would contradict your hypothesis?" and "What constraints could limit your design?" guided revisions to their methods sections. Mid-semester, students completed a metacognitive survey and short reflection responding to prompts such as "How has your understanding changed so far?" and "Where is your reasoning still uncertain?" Prompts were delivered through the course AI assistant and were required components of submitted assignments, ensuring that prompt interaction directly influenced students' reasoning and written work.

The course emphasized three primary learning outcomes: (1) developing the ability to justify engineering decisions using evidence, (2) strengthening scientific communication and argument structure, and (3) increasing awareness of one's reasoning process during design work.
AI-supported prompts were integrated into existing assignments rather than introduced as separate activities. Students interacted with instructor-provided prompts through a customized AI interface, which functioned as a questioning scaffold rather than a solution generator. Prompt responses were incorporated into proposal drafts, experimental plans, and reflective appendices,

ensuring that AI interaction directly shaped graded coursework rather than remaining exploratory.

Assessment Instruments

Metacognitive awareness was assessed using a 24-item shortened version of the Metacognitive Awareness Inventory (MAI) adapted from Schraw and Dennison [6], measuring knowledge of cognition (awareness of strategies, strengths, and task demands) and regulation of cognition (planning, monitoring, and evaluation) (**Table 1**). The survey was administered electronically in the middle of the semester as a descriptive measure aligned with the exploratory nature of the study. Students also completed a retrospective self-assessment of perceived growth in metacognitive monitoring. Scientific communication and project ideation were evaluated using structured rubrics assessing reasoning clarity, evidence alignment, reflective depth, feasibility, originality, and validation planning. Rubric scoring was conducted by the course instructor and analyzed in aggregate form. Quantitative analysis examined descriptive MAI and rubric trends, while qualitative analysis of student writing identified evidence of planning, monitoring, and conceptual revision, providing triangulated insight into student reflection and design thinking within the prompt-led framework.

Table 1. Metacognitive Awareness Inventory (MAI) Used in the Study

Construct	Sub-dimension	What it Measures	Example Student Behaviors Assessed	Item Numbers
Knowledge of Cognition	Strategy awareness	Awareness of learning strategies that work best	Recognizing effective study or problem-solving approaches	1, 7, 12
	Self-knowledge	Awareness of strengths, weaknesses, and prior knowledge	Knowing when one understands or needs help	3, 4, 6
	Task awareness	Understanding task demands and difficulty	Judging which information or methods are relevant	2, 5, 9, 10
	Cognitive awareness	Awareness of how understanding evolves	Noticing conceptual change or growth	8, 11

Regulation of Cognition	Planning	Setting goals and organizing approach before starting	Establishing steps, timelines, or objectives	13, 14
	Monitoring	Checking progress and comprehension during work	Asking self-questions, verifying reasoning	15, 16
	Strategy adjustment	Changing approach when needed	Revising methods after encountering difficulties	17, 18, 22
	Evaluation	Reflecting on outcomes and reasoning quality	Reviewing solutions, assessing evidence, planning improvements	19, 20, 21, 23, 24

Results

The Results section reports descriptive evidence from three sources: rubric-based evaluation of student reports, metacognitive survey responses, and student reflections on AI-supported prompting. Together, these measures provide preliminary evidence of how prompt-guided interaction influenced students' reasoning and written work during the first half of the semester.

1. **Proposed AI-assisted learning framework**

Figure 1 presents a structured framework illustrating progressive AI competency levels alongside their corresponding training content.

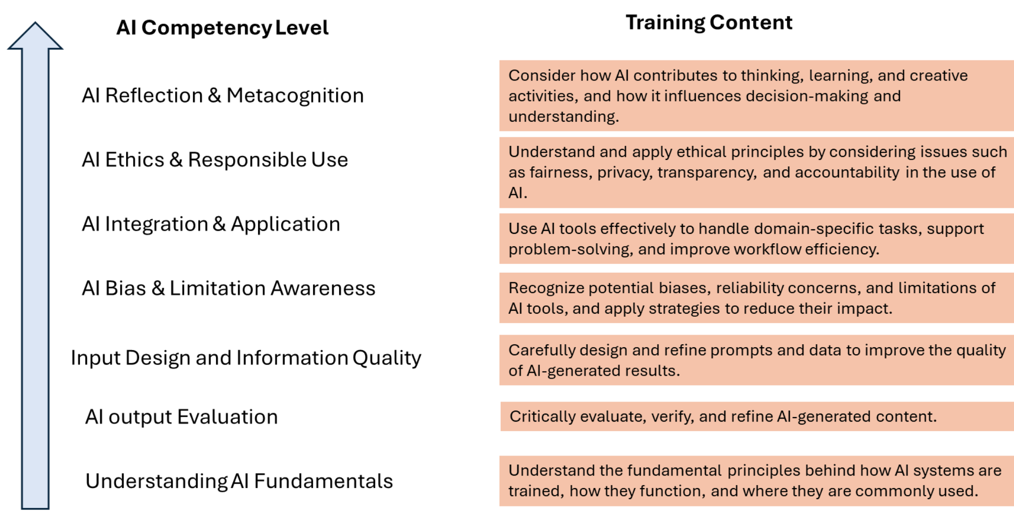


Figure 1. Scaffolded AI Learning framework

2. AI policy in this course

Table 2 shows the current practice being implemented to monitor student learning experience.

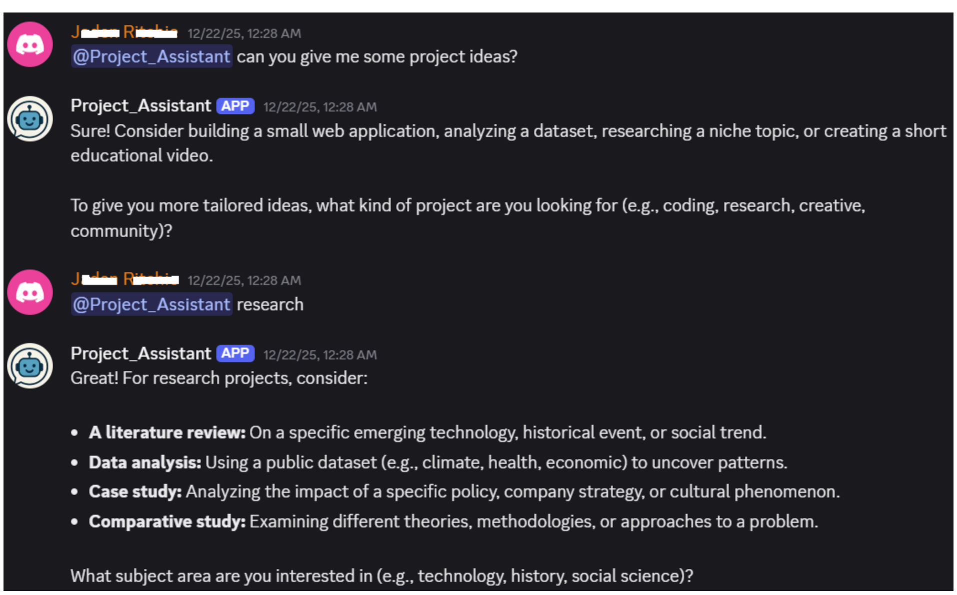
Table 2. AI practise and Policy in the Course

(a) Regular check-in practise	(b) Openness
Anonymous poll: "Does the AI policy work for you?"	Include AI policy in the syllabus
Brief in-class discussion: "How accurate is the AI assistance in relation to your project information?"	Invite student general feedback
Reflection: " Does the AI assistant help you stay organized or move your project forward?	Welcome in-class discussion

Students were not expected to independently judge the correctness of AI outputs. Instead, the course required students to justify any AI-informed reasoning using external evidence, design logic, or course concepts. Rubric criteria emphasized argument quality and evidence alignment rather than agreement with AI suggestions. In this way, the evaluation process focused on students' reasoning rather than the accuracy of the AI itself, reducing reliance on prior expertise.

Figure 2 shows example prompts used in the course**.**

(a) Student interaction with the AI Agent on Idea Brainstorming



(b) AI agent involving in a group conversation including the instructor and student

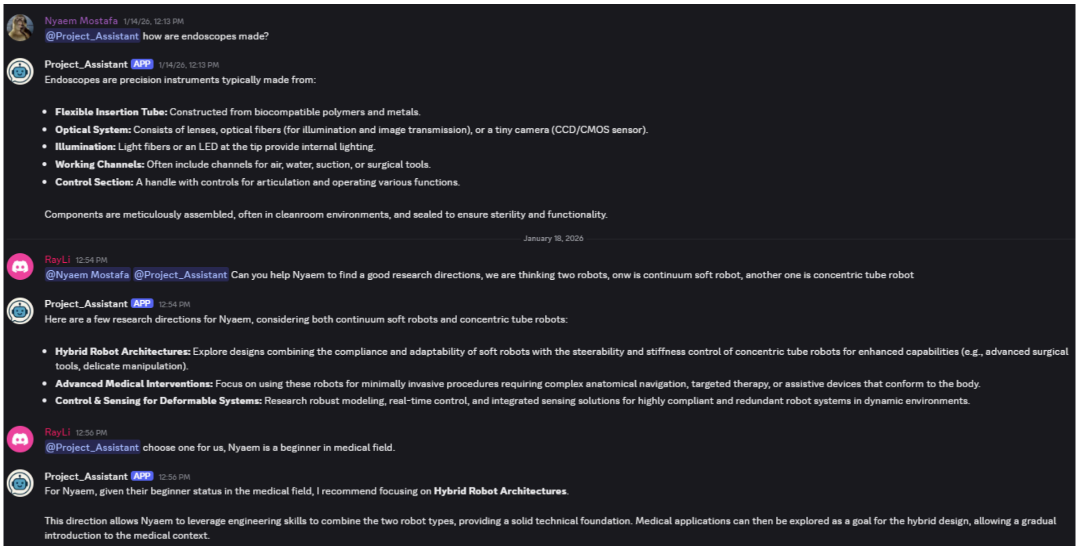


Figure 2. AI agent interaction with single students and student groups.

4. Student Survey Feedback

The pie chart shows perceived accuracy of the assistant's responses to project information. A strong majority, 70%, rate responses as mostly accurate, while 20% consider them very accurate. Only 10% report responses as sometimes inaccurate. Overall, the distribution indicates high user confidence in the assistant's reliability, with limited concerns about correctness.

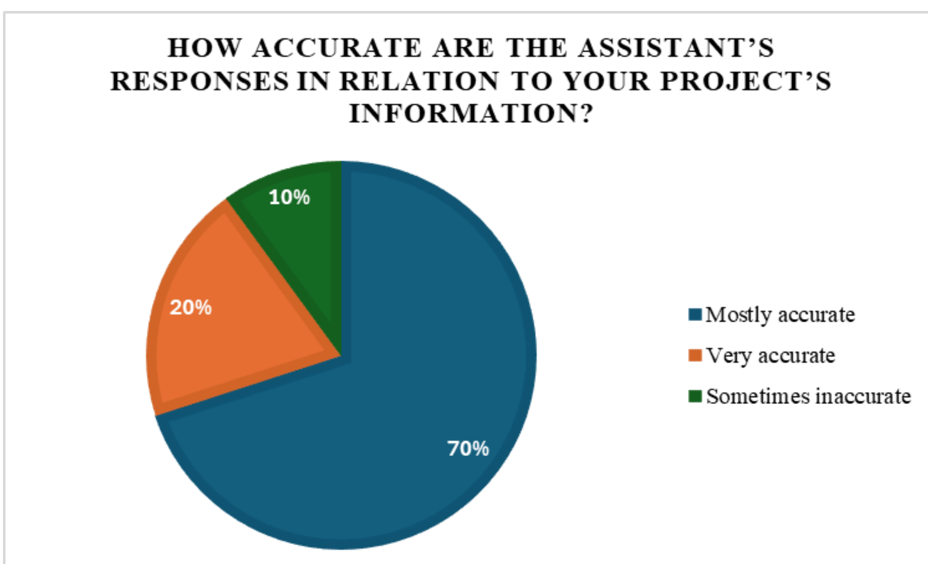


Figure 3. Student Survey Feedback 1

The pie chart illustrates whether the assistant helps students stay organized or move their projects forward. Half of respondents (50%) report that it does help, while 20% say maybe. A further 30% remain neutral. Overall, the results suggest the assistant is generally perceived as supportive, though not universally seen as essential for project progress.

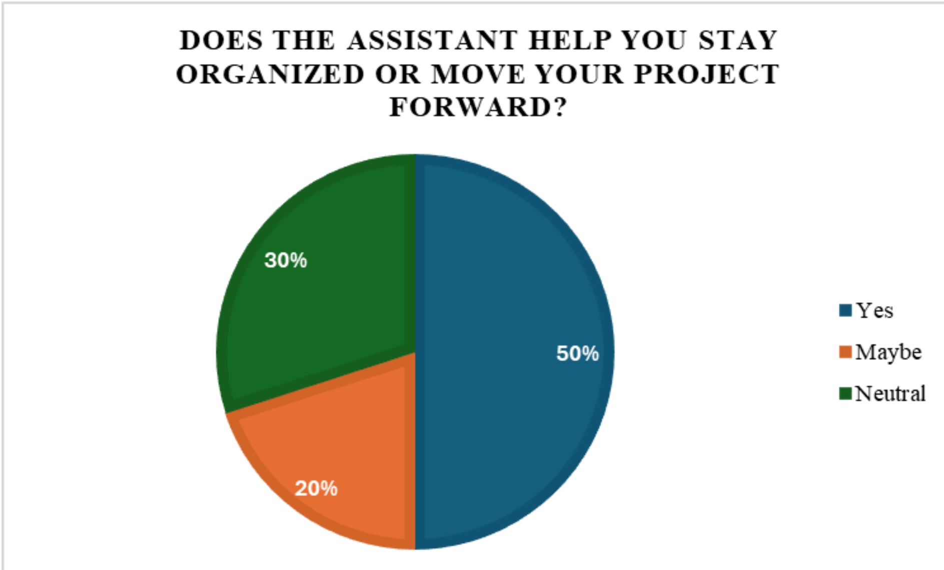


Figure 4. Student survey feedback 2

5. Metacognitive Awareness Outcomes

Analysis of the shortened Metacognitive Awareness Inventory responses (N = 15) indicated moderate-to-high levels of metacognitive awareness among students in the course. The overall MAI mean score was 3.90 (SD = 0.86), suggesting that students generally perceived themselves as actively engaging in planning, monitoring, and evaluating their learning processes. Scores were nearly identical across the two dimensions, with knowledge-of-cognition averaging 3.90 (SD = 0.92) and regulation-of-cognition averaging 3.89 (SD = 0.85). This balance suggests that students demonstrated comparable awareness of both learning strategies and self-regulatory behaviors within the prompt-led learning environment.

Survey responses indicated that students perceived improvements in their metacognitive monitoring over the semester. All 15 participants agreed with the statement, *"Compared to the beginning of the semester, I now monitor my thinking more carefully."* This result suggests that students experienced increased awareness of their reasoning processes during project work. While self-reported and retrospective, this finding aligns with rubric-based observations of improved reflection and justification in student reports.

Discussion

The present study examined how structured prompting integrated into engineering assignments influenced students' reasoning and reflection during the first half of a project-based course. The findings provide preliminary descriptive evidence that students engaged with prompts in ways consistent with metacognitive scaffolding frameworks reported in prior engineering education research. Survey responses indicated that students perceived increased monitoring of their reasoning, while rubric-based analysis suggested improvements in justification and argument clarity across project submissions.

These observations align with prior work showing that structured questioning can support novice learners in articulating assumptions and evaluating evidence during design tasks [12], [15]. Rather than functioning as answer generators, the AI prompts in this study appeared to operate as cognitive cues that encouraged students to externalize reasoning, a mechanism consistent with research on reflective prompts and dialogic feedback in STEM learning environments [14], [16]. At the same time, the present findings should be interpreted cautiously. Because the study involved a single course section and relied primarily on descriptive measures, it does not establish causal learning gains. Instead, it demonstrates the feasibility of embedding structured prompting into engineering coursework and provides initial evidence that such integration may support reflective reasoning processes.

The findings suggest that prompt-led learning can support metacognitive development in first-year engineering students. Embedded prompts encouraged self-monitoring, explanation-building, and iterative reasoning, helping students treat projects as evolving learning processes rather than fixed outcomes. When aligned with instructional goals, AI tools served as dialogic supports that encouraged reflection, while the prompts themselves formed the instructional core. Integrating prompts into project artifacts helped embed reflection within task completion. Limitations include a small single-institution sample and challenges in measuring metacognition. Future work will examine larger cohorts and regulation-of-cognition behaviors. Overall, prompt-led learning shows promise as a scalable approach for integrating AI to strengthen core learning processes.

Conclusion

This study introduced and examined a prompt-led learning framework designed to strengthen metacognition, scientific communication, and creative problem-solving in first-year engineering education. Grounded in metacognitive theory and implemented within a project-based learning environment, the framework embedded structured prompts throughout project ideation, experimentation, and reporting. By shifting reflection from a post-project requirement to a continuous learning process, the approach reframed student work as an evolving record of thinking rather than a static final product. Results indicate that students engaged in prompt-led learning demonstrated strong self-monitoring behaviors, deeper analytical reasoning, and improved coherence in scientific writing.

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