Exploring the Use of Artificial Intelligence as a Tutoring Tool in Engineering Education

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Background

The rapid advancement and widespread availability of artificial intelligence (AI) tools are reshaping educational practices across higher education. However, without intentional instructional design, the use of AI risks encouraging superficial engagement or overreliance on automated solutions rather than supporting meaningful learning [1]. In response, instructors have increasingly shifted from attempting to restrict student use of AI to exploring pedagogically sound ways to integrate these tools into learning environments [2][3]. This shift is particularly critical in engineering education, where conceptual understanding, analytical reasoning, and problem-solving skills are foundational learning outcomes.

Within engineering curricula, the electronics course presents a particularly challenging learning environment. Students must grasp abstract device models, non-linear behaviors, and multi-step analytical processes, while still developing foundational conceptual understanding and problem-solving skills [4]. These challenges make independent learning difficult but also highlight the potential value of AI as an on-demand tutoring resource. Large language models (LLMs) can generate explanations, reframe concepts using multiple representations, and respond interactively to student questions, offering a form of just-in-time support that is not always available through traditional instructional resources [5]. Despite this potential, questions remain regarding how students actually engage with AI in practice and whether these interactions meaningfully support learning in engineering contexts.

Prior work on AI in education has examined its use in intelligent tutoring systems, automated feedback, and, more recently, generative AI tools such as LLMs [6-8]. While some studies report positive student perceptions or efficiency gains, much of the existing research emphasizes performance-based outcomes [9]. Fewer studies examine AI as a self-directed tutoring aid that supports students' independent conceptual exploration, particularly in upper-division or conceptually demanding engineering courses [10]. As a result, there is limited empirical insight into how students interpret, apply, and reflect on AI-generated guidance during their learning process.

Another gap in the literature concerns the role of instructional scaffolding in shaping students' use of AI [11]. Without structured guidance, students may default to using AI as a shortcut to obtain answers rather than as a tool to develop understanding or refine learning strategies. Research on self-regulated learning suggests that reflection, goal-setting, and metacognitive prompts are critical for helping students engage productively with learning resources [12]. However, how such scaffolding can be applied to AI-supported learning in engineering education remains underexplored.

To address these gaps, this study adopts an exploratory action research approach to investigate the use of AI as a self-directed tutoring tool in an undergraduate electronics course. Rather than positioning AI as a replacement for instruction, the study frames AI as a cognitive partner intended to support students' independent engagement with complex course concepts. Students were provided with guided prompts designed to encourage purposeful interaction with AI tools. They were asked to reflect on how they perceived these interactions had influenced their conceptual understanding, learning strategies, and problem-solving approaches. These reflections offer insight into the pedagogical role AI can play when intentionally integrated into an engineering course.

The central research question guiding this study is: How do guided interactions with AI as a cognitive partner influence students' perceived conceptual understanding and learning strategies in an undergraduate electronics course? By examining students' experiences and perceptions, this work contributes to ongoing conversations in engineering education about the instructional potential and limitations of AI. Specifically, the study aims to inform instructional strategies that leverage AI as a productive learning companion, fostering critical thinking and self-regulated learning rather than reliance on automated solutions.

Methodology

Course Description

The electronics course is a required core course in the Electrical and Computer Engineering (ECE) curriculum, focusing on circuit analysis and design involving operational amplifiers (op-amps), diodes, and transistors. Compared to earlier courses such as *Fundamentals of Circuit Analysis*, which introduce basic circuit elements and DC and AC analysis techniques, this course engages students with these concepts at a deeper level. As a result, the course often serves as a critical point for addressing and correcting persistent misconceptions developed in prior coursework.

Students enrolled in the course exhibit substantial variation in their conceptual understanding and prior exposure to electrical and electronic systems. The majority of students (typically 90%-95%) are ECE majors, and the course serves as a gateway to more advanced, discipline-specific upper-division ECE courses. Consequently, developing strong conceptual foundations in this course is essential for students' success in subsequent coursework and for their long-term development as electrical and computer engineers.

Data Collection

Weekly AI-related assignments were implemented during the first six weeks of the semester and were not included in the overall course grade. These assignments were designed to encourage structured and purposeful interaction with AI tools while supporting students' independent learning of course concepts. Each week, students engaged in dialogue with a self-selected AI chatbot and submitted a summary of their interactions with the AI, along with written reflections on the AI's suggestions and their perceived usefulness.

To promote productive engagement, the instructor provided prompts that encouraged students to articulate learning goals, reflect on their learning strategies, and evaluate their conceptual understanding. Table 1 lists sample prompts and tasks for the weekly assignment.

Students were allowed to use any generative AI tools of their choice during the guided activity. Reported usage included ChatGPT (66%), Gemini (20%), Claude (11%), and Copilot (3%). The study did not standardize on a specific AI model, as the focus was on examining students' experiences with AI as a cognitive partner rather than on comparing platform performance.

Prompts were intentionally designed to discourage answer-seeking behavior and to position AI as a personalized tutoring resource that supports conceptual clarification and metacognitive reflection. During the semester, students were informed about the research study, and consent was obtained after the institution's Institutional Review Board (IRB) approved the study as exempt.

Table 1. Sample Prompts and Tasks from Weekly Assignments

"As an engineering student in one of the top 50 universities in USA, what is the most important thing in my study?"
"I need suggestions on how to understand the concept."
"How can I know whether I understand concepts correctly or not?"
"How should I prepare for circuits or electronics labs?"
"Any suggestions on building the circuit?"
"Any suggestions if I want to use AI to help my study?"
There are some very basic concepts from your previous study (current, voltage, power, ground, series, parallel, etc) you can explain to AI and ask AI to tell whether your understanding is accurate or not.
If there is some concept you are not 100% sure about, try to use AI as a tutor and see whether it can explain clearly.
Ask AI to generate some questions to test your understanding of basic concepts.
In each assignment, you can communicate with any generative AI (ChatGPT, Copilot, Gemini, Claude, etc) which you are familiar with. Summarize suggestions/questions AI provided and what you think about these suggestions/questions. Are they good for promoting learning? Do you think this is a good use of AI? Any limitations?

At the end of the semester, students completed a summative reflection on their experiences with AI tutoring. In this reflection, students described how AI influenced their conceptual understanding, learning strategies, and problem-solving approaches as a learning support tool. In addition, one student volunteered to participate in a follow-up interview to provide deeper insight into their experiences. For this study, the summative reflection served as the primary qualitative data source for addressing the central research question: how AI can function as a tutor to support conceptual understanding in an electronics course.

Participants

The participants in this study were 65 students enrolled in an undergraduate electronics course during the Fall 2025 semester. All enrolled students willingly consented to have their reflections included in this study. Of these students, 63 were majoring in Electrical and Computer Engineering (ECE). The cohort included 14 female students and 51 male students. Most participants were junior students taking the course for the first time, while a small number of students (three to four) were repeating the course.

Data Analysis

In this study, we analyzed individual student reflections using an inductive qualitative approach. Each reflection was extracted into a Word document and treated as a discrete unit of analysis. After data familiarization, the reflections were imported into NVivo for systematic coding and organization.

The first author conducted open coding within NVivo, generating data-driven codes grounded directly in students' reflections. As coding progressed, similar or overlapping codes were consolidated to reduce redundancy and improve clarity. Related codes were then grouped into broader thematic categories based on shared meanings and patterns observed across responses.

After the initial coding phase, the first and second authors reviewed the coded excerpts and proposed themes together. The second author examined how excerpts were assigned and whether themes accurately reflected the data. Where interpretations differed, the authors discussed specific excerpts and reached agreement on code assignments or theme structure. Themes were subsequently refined and renamed where necessary to ensure that each represented a coherent and distinct dimension of how AI functioned as a tutoring partner in students' learning experiences.

In the section below, we report on the themes generated from our data: AI as a supplemental tool for classroom instruction, AI facilitation of metacognitive reflection, and recognition of AI's limitations. For each theme, we explain its meaning, describe how it was reflected in the student data, and relate it to existing literature. We also provide unedited quotes as illustrative examples under each theme.

Results and Discussion

Theme 1: AI as a supplemental tool for classroom instruction

This theme captures students' perceptions of AI as a supplementary learning tool that supports formal course instruction. Students frequently described using AI to clarify confusing concepts in electronics, particularly when access to instructors or peers was limited. AI was used to reinforce content from lectures, labs, and course materials, and students often relied on it during independent study, pre-lab preparation, or after-class review. Common uses included asking AI to explain abstract topics such as op-amps and capacitors, break down circuit behavior step-by-step, or translate technical material into simplified analogies.

Within this theme, student responses reflected their view of AI as an extension of classroom instruction. This readily available cognitive partner helped resolve uncertainties before attempting assignments or lab tasks. Similar reports also highlighted AI's potential to support students in comprehending complex concepts [13]. Furthermore, students highlighted AI as a valuable tool that enriched their understanding of course material and extended the explanations provided by the instructor. Several reflections emphasized AI’s value in out-of-class learning contexts, where it offered personalized clarification at moments of confusion. For example, students got confused by the concept “virtual ground” when searching online resources for various design projects. Usually, the circuits course only taught the concept “ground”, and students had not heard of “virtual ground” before. Another example is the “$R_{stability}$” in some op-amp circuits. This is not a concept clearly explained in many textbooks, and even many instructors cannot explain it very well. However, students reported receiving good explanations on such complex concepts, with the help of AIs.

However, across the data, students consistently reported that their core conceptual understanding remained grounded in direct classroom instruction, with AI viewed as a secondary, supportive tool. This observation aligns with prior work, such as Qadir [14], which emphasized AI’s potential to serve as a personal tutor, offering individualized support to learners. However, they also cautioned against treating AI as a replacement for human instruction, stressing the continued importance of teacher-led support. Our data similarly reflects this balance; while students repeatedly described AI as a helpful aid for reinforcing concepts, they did not see it as a substitute for expert, human instruction.

If we had a question in-lab, PLAs or Prof were usually around to give a better answer without needing to ask AI. The AI was good for discussing concepts outside of the lab, and did a good job breaking down specific concepts when prompted.

In the first few weeks, I used AI to get tips on how to analyze circuits and understand lab concepts better. It gave good suggestions like breaking problems into smaller parts and using simulators to see how circuits work.

I suggest still having AI, but only as short, supplementary sections designed to be extra learning outside the lectures, not as a core learning part of the course

Theme 2: AI Facilitation of Metacognitive Reflection

This theme captures students’ engagement with AI-generated learning suggestions, which often prompted them to reflect on and adapt their study practices. Such reflection demonstrates self-assessment, a key metacognitive skill [15]. For example, Table 2 summarizes the AI suggestions on "*How can I know whether I understand concepts correctly or not?*" Several students described using AIs to test their knowledge, particularly in preparation for assessments, by asking them to generate questions or simulate problem-solving scenarios. In some cases, students noted that AI's suggestions led them to rethink their learning approaches, adopting strategies such as breaking down concepts more deliberately or reviewing course material more systematically. These reflections point to students' engagement in self-assessment, planning, and self-awareness, all of which are essential components of effective metacognitive learning [15].

While some students reported limited time or motivation to implement AI-suggested strategies fully, others viewed these suggestions as meaningful and potentially beneficial, even if their impact was not immediately evident. This notable variation depended on self-reported prior learning strategies and academic performance. Notably, among the six students who scored above 90 on the midterm exam, five reported that AI did not substantially influence their learning methods. These students often indicated that they had already developed effective, personalized study strategies and primarily used AI as an information-retrieval or clarification tool, an experience captured in theme 1.

Table 2. Summary of the AI suggestions for students to check their own understanding.

Category	**Percentage**
Explain to someone	37%
Predict & verify	16%
Summarize without notes	14%
Peer review	12%
Self-testing/quizzes	12%
Solve novel problems	7%
Retrieval practice tools	2%

On the other hand, students who scored below 90 on the midterm exam were more likely to describe AI as providing valuable suggestions for improving their learning approaches. Several of these students noted that AI introduced study strategies or ways of engaging with course material that they had not previously encountered. This variation suggests that AI may be perceived to play a more significant metacognitive role for students who are still developing effective self-regulated learning strategies.

Furthermore, within this theme, we observed that the guided prompts that encouraged students to articulate goals, explain concepts, and evaluate their understanding helped them frame AI interactions as opportunities for reflection rather than answer generation. These findings align with prior research emphasizing the importance of scaffolding in fostering metacognitive development [15]. They also support emerging work suggesting that AI tools can facilitate self-exploration and reflective learning when used intentionally [16].

Overall, this theme highlights AI’s potential to function as a metacognitive catalyst, particularly for students who lack well-established learning strategies. By encouraging reflection on how they learn and offering alternative approaches, AI supports students’ awareness of their own learning processes. These findings also indicate that enhancing learning strategies is a gradual process that benefits consistent practice and sustained effort over time.

Yeah, AI actually gave me some pretty solid suggestions….. It also helped me come up with practice questions to test myself on stuff like capacitor impedance and how integrators work. The tips about checking extreme cases and connecting the math with the actual circuit diagrams were helpful too.
Trying to predict what will happen forces me to think about the problem then apply what I learned from the lecture to it. If I get it wrong it shows the weakness in my understanding of the concept
I thought they were good but they didn’t help me study.
I didn’t find a use for new learning methods suggested by Ai, as I felt my own methods were more tuned to how I study and learn.

…. AI gave me a lot of helpful suggestions for improving my study habits and preparing for labs. The advice was practical and made sense, and when I did follow it, I could tell it made studying and understanding the material easier. Unfortunately, I haven’t been very consistent in applying those tips, and I can see that reflected in my recent grades and overall performance.

Theme 3: Recognition of AI limitations

Students’ recognition of AI's limitations is captured within this theme, even as they acknowledged its benefits in supporting understanding and providing accessible assistance. While many students perceived AI as helpful in specific contexts, they also noted that it frequently offered generic, repetitive, or overly familiar learning strategies. Our findings align with Qadir [14], who emphasizes the importance of users applying due diligence and maintaining awareness of AI’s limitations, rather than placing blind trust in its outputs.

Several students also reported that AI struggled to explain complex course concepts, with explanations that either lacked depth or failed to provide clarity where support was most needed. In some cases, students found the AI-generated suggestions irrelevant or unhelpful, leading them to discontinue using it. Suggestions such as using the Pomodoro technique, reviewing slides, or practicing active recall were strategies students had already encountered throughout their academic careers, making the advice feel redundant and lacking originality.

A few reflections raised concerns about the accuracy of AI’s explanations, mainly when it produced incorrect or misleading information. Vidalis et al. [13] identify similar concerns around accuracy in their study, aligning with our observation of drawbacks associated with AI. However, unlike their findings, we did not observe overreliance on AI in our data.

Students in our study appeared to perceive AI's role as a supplement, consistent with the pattern described in Theme 1, rather than as a primary instructional tool. These observations reflect students' growing discernment in evaluating AI's educational value, appreciating its support in some situations while questioning its reliability, novelty, and overall usefulness in others.

Interestingly, this theme also reflects the value of guided prompts in facilitating self-directed exploration as through students' engagement with AI they discovered and articulated its limitations. This act of questioning AI output and critically evaluating its suggestions echoes what Darwin et al. [17] describes as questioning norms and reasoning effectively, essential components of critical thinking that are increasingly relevant in students' use of AI.

I tried all of the suggestions that AI gave, but only because they were so generic and obvious for studying in the first place.

I feel that honestly AI only helped me with basic concepts of the circuits but not necessarily good study habits or methods. I tried to do a couple of flashcards or communication reviewing with the AI to understand better but I felt it was not helpful as it just parroted the same points over and over. I think in the future, the textbook and class are better resources.

Sometimes, when I try a suggestion it usually works, but sometimes the AI is wrong and you don't really have any way of knowing when that is if you rely on the AI for an answer.

Implications

A key contribution of this study lies in students' ability to actively integrate AI into their coursework and subsequently reflect on its role in their learning. While students had previously engaged with AI by responding to its suggestions, the structured opportunity to reflect on how they used AI provided first-hand insight into its function as a tutor. This suggests that for AI to serve an educational role beyond content delivery, learners must be supported not only in accessing AI but also in reflecting on its use, enabling them to recognize when and how AI has (or has not) contributed to their understanding.

The findings related to AI's supplementary role, perceived limitations, and metacognitive potential offer practical implications for instructors seeking to meaningfully integrate AI into their teaching. Rather than focusing solely on the development of custom models, educators may consider how general-purpose AI tools can be embedded into courses as tutoring aids that support clarification, conceptual reinforcement, and self-regulated learning. Additionally, the variation we observed in students' perceptions of AI's metacognitive value, particularly regarding academic performance, holds important practical implications for instructors. It is essential that AI is not implemented as a one-size-fits-all tutoring resource, as some students may find limited benefit from it, while others may rely on it more heavily to support their learning needs.

The metacognitive engagement observed in students' reflections also holds implications beyond this specific course. Several students noted that AI strategies explored through guided prompts in this course were later applied in other academic contexts. This highlights the potential for AI to serve not merely as a course-specific aid but as a transferable academic tool, supporting students across disciplines and over time.

Our approach, which involves providing multiple scaffolds prior to reflection, appears to have been effective in supporting students' productive engagement with AI. These scaffolds served as flexible guardrails, offering structure without constraining autonomy, and enabled students to explore AI's capabilities in ways that were both critical and personally meaningful.

Limitations and Future Work

This study has several limitations that should be considered when interpreting the findings. First, the study was conducted within a single undergraduate electronics course at one institution and was facilitated by a single instructor. As a result, the findings may not be generalizable to other courses or instructional designs. The authors will employ this strategy in a sophomore-level ECE course this semester. In addition, we will recruit more students for interviews, enabling us to examine broader impact factors such as prior academic performance and gender.

Second, the primary data sources consisted of student self-reported experiences. While these reflections provide valuable insight into students' perceptions and learning processes, they do not directly measure conceptual understanding or learning gains. Students' responses may also be influenced by prior learning experiences or a desire to present their experiences in a favorable light. Future research could incorporate complementary measures, such as performance data or comparison groups, to examine the relationship between AI-mediated tutoring and demonstrable learning outcomes.

Third, the AI-related assignments were only implemented during the first six weeks of the semester. Because the development of effective learning strategies and metacognitive skills often occurs over extended periods, longer-term implementation is helpful for observing clearer, more accurate outcomes in future work.

Despite these limitations, the study provides meaningful exploratory insights into how AI can function as a self-directed tutoring resource in an electronics course when supported by guided prompts and reflective scaffolding.

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