Integrating Personalized AI-Assisted Instruction Into Remote Laboratories: Enhancing Engineering Education With OpenAI's GPT Models

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***Abstract*—In recent years, remote laboratories have become integral to modern education, offering flexibility and accessibility compared to traditional, in-person labs. Integrating AI-powered assistance into remote labs has the potential to give them an edge by providing personalized learning experiences. This paper explores an innovative approach to promoting independent learning and critical thinking by embedding AI-driven support, using OpenAI's GPT-4 model, into a remote Field Programmable Gate Array (FPGA) laboratory. Through a web-based code editor, students write SystemVerilog programs and receive tailored assistance from the AI, while their designs are deployed on a Terasic DE1-SoC FPGA development board with real-time feedback via a live camera feed. The study, which involved students from an advanced digital design course interacting with the AI assistant, revealed strong engagement and positive feedback. Preliminary results indicate that AI-powered guidance can meaningfully boost student involvement, providing a scalable and effective framework for fostering active learning in engineering education.**

***Index Terms*—AI assistance, remote laboratories, engineering education, GPT models, personalized learning**

I. Introduction

Remote learning and laboratory environments have gained significant popularity in recent years, largely due to their ability to offer flexibility and promote equity among students from diverse backgrounds and with varying capabilities [1]–[4]. Unlike virtual labs, which simulate hardware, remote laboratories allow students to interact with physical hardware in real time, providing a more hands-on experience [5], [6]. Numerous studies have demonstrated the effectiveness of this approach, with research indicating that remote laboratories can lead to enhanced learning outcomes and improved assignment completion rates compared to other formats [7]–[9]. Concurrently, the adoption of generative pre-trained transformer models in educational environments has increased significantly since the release of these tools to the public [10]–[13]. Recent studies have explored how these new tools can influence the pedagogical environment [14]–[17]. Remote laboratories are continually evolving through the integration of new technologies designed to enrich the learning experience. One notable advancement is the adoption of personalized AI coding assistants, which streamline the coding process by reducing debugging time, improving coding practices, and enhancing overall programming skills development.

Personalized AI coding assistance has become a widespread feature in many popular coding platforms [18]–[21]. Research indicates that such tools can enhance the coding experience by assisting users in debugging and auto-completing code segments without compromising their ability to code independently [16], [17]. This technology not only streamlines the coding process but also accelerates learning by providing real-time feedback and suggestions, allowing coders to focus on strategic aspects of programming rather than syntax errors [22], [23]. Additionally, the integration of AI coding assistance in remote laboratories could significantly benefit students by offering tailored support and adaptive learning paths. This capability enriches the educational experience, enabling students to engage more deeply with the material and apply their

knowledge more effectively in practical scenarios [24], [25].

This paper outlines the adaption of a personalized AI Assistant tool, using OpenAI's GPT models, to a particular pedagogical setting. This study involved students enrolled in a junior-level digital design course (EE/CSE 371) working on a lab assignment that focused on programming FPGAs (Field Programmable Gate Arrays) using SystemVerilog. The task required students to develop code for a DE1-SoC FPGA development board to simulate a real-world parking lot system, which was visualized through a 3D simulator. [26]. Designed to support students, the tool assists with debugging, provides guidance, and encourages inquiry without giving direct solutions to problems. It promotes independent learning and critical thinking by allowing students to engage through predefined questions or an open-ended chat interface. In addition to enhancing the student experience, the AI tool also streamlines the work of teaching assistants by serving as a personalized tutor, allowing them to focus on more complex instructional tasks rather than routine questions. At the conclusion of the course, students were invited to complete an anonymous survey, which was analyzed using both qualitative and quantitative methods.

II. Technical Approach

A. The AI-Assistant Frontend

The AI-Assistant was integrated into LabsLand's FPGA labs for the duration of the study. Within the laboratory interface, students had access to three distinct tabs: a Files tab, an HDL Code tab, and the newly introduced the AI-Assistant Chat tab. In the chat tab, as shown in Figure 1, students were informed about the possibility of encountering errors and that all interactions would be recorded for analysis purposes. To facilitate their experience, a set of pre-formulated questions was provided, while also allowing students the flexibility to type in their own queries. The chatbot was designed to read and interpret the user's code, enhancing the interactive learning experience.

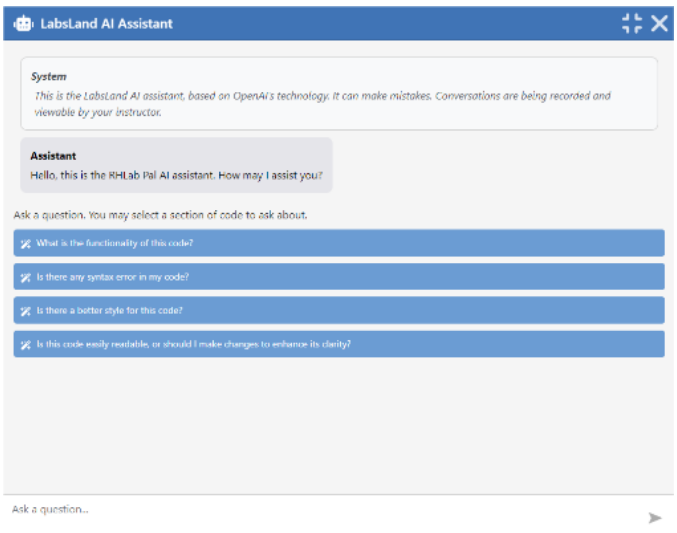

Fig. 1. The user interface of the AI Assistant.

B. The AI-Assistant Backend

The AI-Assistant provides an admin tab accessible to authorized personnel, allowing them to modify and configure the model being utilized, including the context, instructions, and the current assignment prompt. For this particular offering of EE/CSE 371, a GPT-4 Turbo model was employed. The context, instructions, and assignment prompts were tailored specifically towards the Parking Lot lab of the EE/CSE 371 course. Additionally, the AI-Assistant incorporates a data tab, enabling instructors to monitor and analyze students' interactions with the AI tool.

C. Integration of Curriculum

The AI-Assistant was integrated into EE/CSE 371 during the winter quarter of 2024. This class provides students with both theoretical knowledge and practical experience in utilizing tools and techniques for modeling complex digital systems through the SystemVerilog hardware description language.

III. Framing Survey Questions

After the lab assignment deadline, students enrolled in the course were invited to complete an anonymous survey aimed at evaluating and reflecting on their experience with the AI assistance. The primary goal of the survey was to assess the effectiveness of the AI-assisted learning tool in enhancing student engagement, understanding, and problem-solving skills within the remote lab environment. All students, including those who did not use the AI tool, were invited to share their perspectives and perceptions on the concept of incorporating such a tool into education, ensuring a broad range of feedback. The questions are organized into four distinct categories as outlined in Table I:

A. Usability and Engagement

These questions assess how intuitive and user-friendly the AI assistant is. They help understand whether students found the AI tool easy to navigate and integrate into their lab work. Evaluating ease of use is crucial for determining if the tool can be effectively adapted without adding complexity or frustration to the learning process.

B. Judgment of AI Assistant's Pedagogical Capabilities and Educational Experience

These questions explored how the AI assistant impacted students' understanding, problem-solving skills, and overall educational experience. By collecting students' feedback on their problem-solving experiences and gathering detailed instances of how the AI assistant addressed their queries, educators can assess whether the AI tool achieves educational goals and promotes deeper engagement with the assignment.

C. Comparative Evaluation

These questions compared the AI assistant with traditional learning methods, such as interactions with human teaching assistants. The questions allow students to reflect on their preferences for using the AI assistant versus traditional methods.

TABLE I
STUDENT SURVEY BREAKDOWN

Question Category	Pharasing	Response Type
Usability and Engagement	The AI assistant was easy to use in the context of completing lab assignments.	Likert Scale
	I felt more engaged in the Lab assignments when using the AI assistant.	Likert Scale
	Using the AI assistant improved my understanding of the lab material.	Likert Scale
	The personalized feedback from the AI assistant enhanced my learning experience.	Likert Scale
Judgment of AI Assistant's Pedagogical Capabilities and Educational Experience	The AI assistant effectively addressed specific questions and concerns.	Likert Scale
	The integration of the AI assistant into the lab assignments met my educational needs.	Likert Scale
	How did the personalized nature of the AI assistant's feedback affect your approach to learning and problem-solving in the lab?	Open Response
	Can you provide an example of how the AI assistant helped you overcome a particular challenge in a lab assignment?	Open Response
	The AI assistant provided helpful guidance without giving away the answers directly.	Likert Scale
	Describe your overall experience using the AI assistant for completing lab assignments. What aspects did you find most beneficial?	Open Response
Comparative Evaluation	I would prefer using the AI assistant in future lab assignments over traditional methods.	Likert Scale
	How did using the AI assistant compare to seeking help from a teaching assistant during office hours? Did you find one more beneficial than the other? Please explain	Open Response
	The AI assistant reduced the frequency with which I sought help from TAs during office hours.	Likert Scale
	Has the AI assistant influenced the way you would normally seek help during office hours? If so, how?	Open Response
	The interactions with the AI assistant closely resembled those I would have with a human teaching assistant.	Likert Scale
Suggestions for Improvement and Feature Request	In what ways could the AI assistant be improved to better support your learning in lab assignments?	Open Response
	How do you perceive the role of AI assistants like this in the broader context of engineering education?	Open Response
	Are there any additional features or support you wish the AI assistant could provide in future lab assignments?	Open Response
	Please use this space if you have any additional comments related to your perception or experience that wasn't covered in these questions.	Open Response

Insights gained can help determine the relative value of AI tools in educational settings and guide future integration of technology-based learning aids.

D. Suggestions for Improvement and Feature Request

These questions sought feedback on how the AI assistant could be improved and gathered suggestions for additional features. Student feedback on usability issues, desired features, and overall satisfaction with the assistant provides direct input into future upgrades and innovations. These insights ensure that subsequent versions of the AI assistant are more closely aligned with student needs and preferences.

IV. SURVEY RESULTS AND FINDINGS

This section presents the findings of the anonymous survey designed to assess the effectiveness of the newly implemented AI assistant within a web-based code editor, focusing on its impact on user experience. From the total of 53 students enrolled in the course, 36 completed the survey, resulting in a participation rate of 63.2%. The analysis derived from their responses offers valuable insights into the perceived benefits and areas for improvement of the AI tool, providing a comprehensive understanding of its utility in an educational setting.

A. Quantitative Results

As depicted in Figure 2, among the respondents who utilized the tool, 40% expressed a positive response to the usability and engagement of the AI assistant, awarding it an average rating of at least 4 out of 5. Conversely, 60% of the users gave a neutral to positive rating, ranging between 3 and 4. Notably, no students rated their experience below 3. The average score was computed by aggregating each student's response score to the questions within this category and then dividing it by the total number of questions. These findings indicate that users generally found the AI assistant user-friendly and beneficial to their lab assignments, noting improvements in engagement, comprehension, and the overall learning experience within this particular lab context.

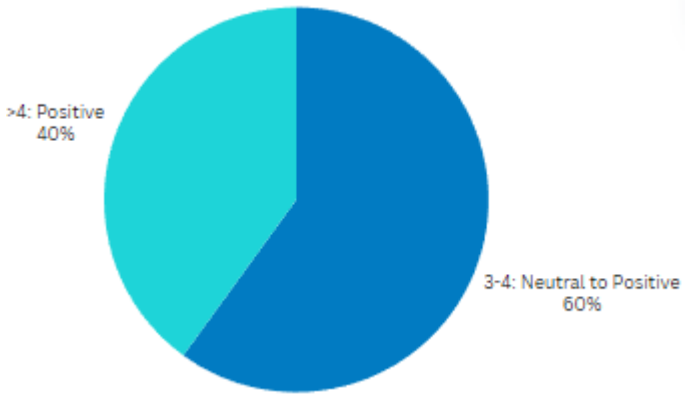

Fig. 2. Usability and Engagement results.

Figure 3 summarizes the average ratings for all Likert questions in the second category, which focuses on the AI assistant's pedagogical capabilities and educational impact. 20% of users gave a positive rating of at least 4, 66.7% provided a neutral to positive rating between 3 and 4, and 13.3% issued a neutral rating between 2 and 3. No students assigned an average rating below 2. While some students acknowledged that the AI assistant effectively addressed their queries about their SystemVerilog code and met their educational needs without directly providing answers, the majority felt that the responses from the AI assistant could be improved.

Figure 4 provides a summary of the results for the Likert-scale questions within the "Comparative Evaluation" category. A small fraction of students, 6.7%, expressed strong positivity about the effectiveness of the AI assistant in comparison to human teaching assistants, indicating that the AI could offer comparable or superior assistance. The majority, 66.6%, had a neutral to positive view, suggesting a general acceptance or mild approval of the AI assistant as an effective tool, while 26.7% had a neutral view in their assessment, reflecting some reservations or dissatisfaction with the AI assistant when compared to the traditional human interaction.

All four questions in the final category, which prompt students to suggest improvements and features they would like to see, are formatted as short-answer responses. The results of these questions will be discussed in the following section.

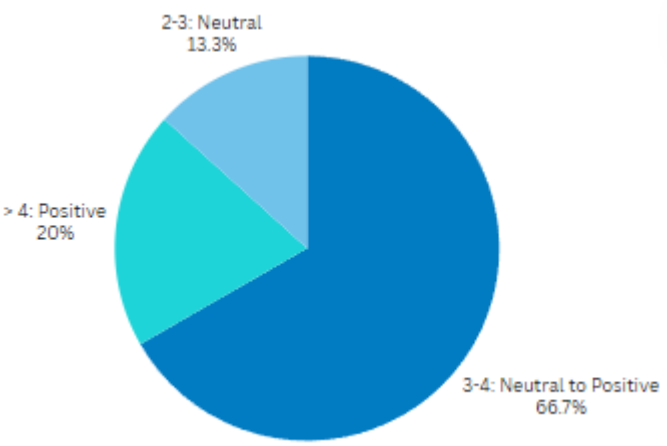

Fig. 3. Pedagogical Capabilities and Educational Experience results.

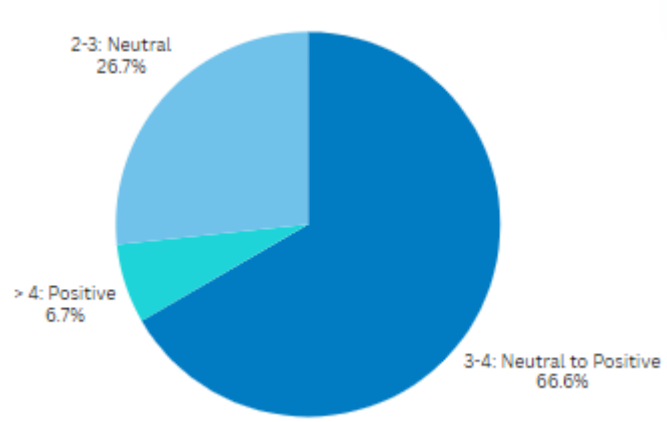

Fig. 4. Comparative Evaluation results.

B. Qualitative Results

This section presents the findings from all the open-response questions along with their analysis. The questions are organized according to the same categories used in the quantitative section. However, the first category, Usability and Engagement, contains only Likert-scale questions and is not included in this discussion.

1) Judgment of AI Assistant's Pedagogical Capabilities and Educational Experience:

Theme 1: High debugging performance

> *"I found the AI assistant to be useful for debugging things like syntax errors or minor logical mistakes. It's much better at noticing things like a missing semi-colon than a human is, so in that sense it enhances productivity."*

66.7% of the students reported that the AI assistant was highly effective in identifying bugs in their code and enhancing code structure. This efficiency allowed them to spend less time

on debugging and more time on learning course materials. Additionally, it facilitated faster prototyping, contributing to a more streamlined and productive learning process.

Theme 2: Detailed code explanation and commenting suggestion

> *"The premade prompts made it much easier to check for missing comments, correct design patterns, and explain what was going on in the code. It made work I turned in was of better quality without having a TA review each file."*

13.3% of students appreciated the code explanation provided by the assistant, and 13.3% of them found the suggestions on how to correctly comment on their code particularly useful, which constituted a substantial portion of their lab assignment grade. This aspect of coding, often overlooked, is crucial for maintaining clear and understandable code, which not only aids in debugging but also facilitates collaboration.

2) Comparative Evaluation:

Theme 1: Human assistants are irreplaceable

> *"I find TA office hours more beneficial. They always provide clear explanations and a deeper, more intuitive understanding of the material."*

An overwhelming majority of students (93.3%) maintained that human teaching assistants are an irreplaceable element of a course, citing their ability to provide more accurate answers, explain concepts more intuitively, and offer better guidance on approaching lab assignments. The AI assistant often offers various possible solutions to a question and does not provide as direct guidance as a teaching assistant (TA) during office hours. Students find the immediate feedback and direction offered by TAs more beneficial for more assured problem-solving.

Theme 2: Shifting help-Seeking behaviors

> *"Through using the AI assistant, while I still made my visits to OH in terms of needing help to troubleshoot code or such like that, the AI assistant was definitely the first tool that I used when trying to get my thoughts sorted out, or to try to receive answers to any questions that I may have had. If the responses that I received weren't particularly useful or didn't provide enough clarity, then I would go to seek help during office hours instead."*

Furthermore, nearly half of the respondents (46.6%) reported that the introduction of the AI assistant altered their approach to seeking help, with many opting to consult the AI assistant first before turning to human teaching assistants. Additionally, 20% explicitly stated that their reliance on human teaching assistants for help has decreased as a result of using the AI assistant, indicating a shift in how they access support during the course. The decrease in dependency on human assistants suggests a potential reduction in the workload for human teaching assistants, allowing them to focus more on complex queries and personalized instruction.

3) Suggestions for Improvement and Feature Request:

Theme 1: Inclusion of AI assistants benefits education

> *"I see AI assistants as becoming an integral part of engineering education, as they can allow students to focus more on concepts and understanding rather than debugging."*

Students unanimously viewed the inclusion of AI assistants in engineering courses as beneficial, citing their support for self-assisted learning, inclusivity, and greater flexibility compared to human teaching assistants. They appreciated how AI assistants facilitated a more individualized learning experience, allowing them to work at their own pace and access help on demand.

Theme 2: Supplemental nature of AI assistants

> *"I believe the role of AI assistants in engineering education should be to supplement education rather than supplant it. I think engineering students should use AI assistants for tasks that optimize their work while not diminishing their competence or skills. In simplicity, I think they should be a guide."*

40% of the respondents highlighted that, given the current limitations and imperfections of the AI model, these tools should be used to complement the work of human teaching assistants rather than replace them entirely. This perspective underscores the need for a balanced approach where AI tools enhance educational experiences without undermining the crucial human element. By offering students both options, they can select their preferred method of assistance based on their specific needs, thereby making education more inclusive and accessible.

Feedback on potential improvements for the AI assistant was also collected. The most commonly suggested enhancements were to increase the resources available to the AI assistant and to improve its user interface. Many students believed that by providing the AI with more access to lecture materials, it could perform better in addressing questions related to course content and concepts. Additionally, some students highlighted the need for a more user-friendly interface. A few responses called for the AI assistant to deliver more concise answers, the ability for users to halt the AI assistant's response generation, and the option to share the AI assistant among group members.

Overall, the feedback indicates that while students were generally satisfied with the AI assistant's performance, particularly in aiding with debugging, there is a strong interest in expanding its features to provide more comprehensive guidance on lab assignments and course materials.

V. Discussion and Limitations

A. Discussion

The results of the anonymous student survey regarding the integration of the AI assistant in the remote laboratory were predominantly positive. A majority of the students responded

favorably to the inclusion of the AI assistant, appreciating its ease of use, constant availability, and the valuable guidance and answers it provided, which enhanced their engagement and understanding of the lab assignments. Even students who did not utilize the AI assistant during their assignments expressed positive views, suggesting that they believe the AI could enhance their learning experiences and outcomes in future labs. However, despite the general positivity, many students held neutral or negative views regarding the AI assistant's ability to reduce the time they seek help from teaching assistants. This sentiment stems either from the AI assistant not fully replicating the human assistant experience or a simple preference for human-to-human interactions. At the time of writing this paper, the AI assistant has been upgraded to utilize the GPT-4o model, which is expected to enhance the overall user experience by generating more accurate responses at a faster speed for future students.

These findings carry significant implications for the teaching and learning in electrical and computer engineering courses and related fields. By integrating this AI feature, instructors not only enhance educational outcomes but also promote inclusivity and accessibility. All students, regardless of background, have the opportunity to receive help as needed, which improves equity without adding extra workload for instructional teams.

B. Limitations

Several limitations of the study are important to acknowledge. Firstly, the survey had a response rate of 63.2% from a class of 53 students, resulting in a relatively small data sample. A larger class size might provide a more comprehensive and accurate analysis. Secondly, more than half of the students who participated did not use the AI assistants, as their use was optional and concerns about privacy and data collection might have deterred some from utilizing this resource, thereby limiting the amount of user feedback collected. Thirdly, the study was conducted at a single, well-funded university where the majority of students have access to computational devices and stable internet connections. This setting may not accurately reflect the experiences of underrepresented groups who lack access to such resources, thus limiting the study's diversity and generalizability. Lastly, the survey responses were largely subjective, based on students' experiences interacting with human teaching assistants and the AI assistant, which was used for only one assignment. Like other studies involving this novel technology, measuring the tangible benefits of the AI feature is challenging without a comparative analysis between a test group and a control group.

VI. Current Ventures

While the AI assistant has been well-received by the class, it has not yet achieved the level of personalization offered by human teaching assistants, who provide in-depth guidance and clarify assignments. The current the AI-assistant model effectively assists students with writing and understanding SystemVerilog code, but it has the potential to offer more tailored assistance with further development. Enhancing the model through deeper training and incorporating more assignment-specific resources could allow for more accurate and personalized help. However, a more proficient model also carries the risk of leading to answer leakage, an issue the research team has already encountered on a few occasions while training the AI assistant. Therefore, any improvements to the AI assistant must be carefully managed and thoroughly tested to prevent unintended dissemination of answers, ensuring that the tool supports learning without compromising academic integrity before it is released for broader student use.

VII. Future Work

As we continue to refine the AI assistant, future work will focus on expanding its use across different remote laboratories and educational contexts while closely monitoring student engagement and feedback. A key area of improvement will be enhancing accessibility features, such as integrating tools for visually impaired students, including text-to-speech output and voice control, to ensure equitable access for all learners. Additionally, better integration with course materials will be explored, allowing the AI assistant to provide more precise and context-specific feedback by training the model with relevant coursework, homework solutions, and lab assignments.

Future studies will also investigate the long-term impact of AI assistance on students' problem-solving abilities, critical thinking, and engagement across a wider range of courses, including other areas within electrical and computer engineering. This will help us assess the broader potential of AI-driven learning tools in STEM education. Collaboration with teaching assistants will be further examined to optimize the balance between AI support and human instruction, ensuring the tool enhances, rather than replaces, the valuable contributions of instructional staff.

Expanding the study to include more diverse student populations and remote lab configurations will provide deeper insights into how AI can support inclusivity and accessibility. As AI in education rapidly evolves, the assistant will require continuous monitoring and updates to stay aligned with technological advancements and emerging regulations. By addressing these areas, we aim to improve the tool's effectiveness in fostering personalized learning and inclusivity in remote labs.

VIII. Conclusion

In this paper, we demonstrate the potential of AI-driven assistance in remote laboratories to enhance student engagement, promote independent learning, and foster critical thinking in digital system design education. By providing personalized guidance through AI tools, students are able to navigate complex coding tasks more effectively while receiving support tailored to their individual needs. This approach not only benefits students but also streamlines the workload for instructional teams, allowing educators to focus on higher-level teaching responsibilities.

As highlighted in this paper, the AI assistant exemplifies the transformative potential of this technology, offering students relevant guidance whenever and wherever they need it. The promising feedback from students underscores the role of AI tools in fostering not only immediate educational outcomes but also a positive relationship between learners and emerging technologies. The ongoing development and refinement of these tools present an exciting trajectory for future pedagogical advancements, ensuring that learners are informed, inspired, and prepared for the challenges and opportunities of the digital landscape.

As AI becomes an increasingly integral part of education, it is crucial to find ways to coexist with these technologies while preserving the integrity of the learning experience. The AI assistant represents a research-backed approach to effectively incorporating AI assistance into educational settings, ensuring that students benefit from personalized learning without compromising the educational process. By continuing to explore and refine these technologies, we reaffirm our commitment to advancing equitable, accessible, and impactful learning environments for all students.

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