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TIC-TOC: Enhancing Industrial Control Education through an Intelligent Tutoring System for Real-Time Interaction and Engagement [Draft!]

This was our first research project and it was never submitted or published.

Abstract

The urgent transition to online learning as a result of the COVID-19 pandemic highlighted the need for advanced online learning tools. The rise of commercially available large language models (LLMs) and their APIs enables the creation of free and scalable solutions that facilitate ubiquitous learning. LLMs are customizable through adjustable parameters (such as temperature and token limits), refined via prompt engineering, and the model itself can be fine-tuned with domain-specific data, allowing for more targeted and effective educational applications. To enhance the effectiveness of industry control, automation, and Industry 4.0 education, we must utilize these technologies to further expand ubiquitous learning in STEM. We present a novel approach to industry control learning. With consideration of student's needs and other industry learning approaches, while simultaneously taking advantage of the rise of commercially available LLMs and their APIs, we created a personalizable Intelligent Tutoring System (ITS) that can adapt to student's needs and provide personalized feedback. Our ITS, which we've named Tutor for Industry Control (TIC), allows for dynamic assessments for students and progress tracking and content management for instructors. Students can engage with the adaptive assessments, gradually increasing their mastery levels across various topics, while benefiting from real-time feedback from the integrated chatbot. Instructors can customize content, add topics, and monitor individual student progress.

Introduction

The integration of AI technologies in educational settings, as discussed in recent research, demonstrates significant benefits for both students and instructors. AI applications such as adaptive learning, intelligent tutoring systems, and virtual classrooms not only enhance the quality of instruction provided by teachers but also improve student learning outcomes by offering personalized and engaging educational experiences [1]. This dual advantage underscores the potential of AI-driven tools to revolutionize traditional teaching and learning methods, making education more effective and accessible for all stakeholders.

Studies indicate that while there is sometimes a preference for face-to-face learning among higher-education students [1], online learning offers tremendous benefits for some students such as time-saving, comfort, and accessibility, which are crucial for students with work commitments or other constraints [2]. The COVID-19 pandemic has significantly influenced students' learning preferences and habits. The sudden shift to online learning highlighted both the advantages and challenges of this mode of education, emphasizing the need for improved online learning tools [3]. Traditional online learning methods often fall short in maintaining student engagement and providing real-time interaction and feedback [4]. An intelligent tutor can help bridge this gap by offering personalized assistance and emulating professors genuine feedback.

The need for more effective methods as a result of the shift to online learning has further proven that AI chatbots can offer better learning opportunities for students [5]. The use of these chatbots have proved to be effective in their ability to provide an accessible and quick educational tutor while decreasing the workload for the instructors. [6]. Creating personalized learning experiences using an AI-based ITS will allow students to feel more involved and engaged throughout their learning experiences, furthering the idea that learning should not be limited by students' accessibility and limited resources.

Leveraging the advent of commercially available LLMs [7], their APIs, and fine-tuning capacities with a cloud-based infrastructure can provide highly scalable and individualized intelligent tutors that are accessible to a broader range of students, including those in underdeveloped regions with limited access to physical resources [8]. Combining the strengths of face-to-face learning with advanced online tools can create a more holistic and effective educational experience.

A chatbot with a familiar interface specifically tailored for industrial control can enhance this blended approach by offering continuous, on-demand support, bridging the gap between STEM and Ubiquitous Learning [9] and furthering sustainable education [10]. *"Technology becomes an invitation to do things better, sometimes in ways that some people have been saying for a long time they should be done"* (Cope & Kalantzis, 2010).

Related Work

Previous studies have explored the potential of large language models (LLMs) and intelligent tutoring systems (ITS) in various educational contexts. One study [11] at a small, engineering-focused R1 university developed a virtual teaching assistant using LLMs, showing that custom implementations of course-specific LLM agents could be more effective for supporting student learning compared to general-purpose conversational agents like ChatGPT. This study also highlighted the increasing acceptance and perceived benefits of LLMs among students, with significant usage reported despite some concerns . Another research [12] focused on secondary students' use of ITS for English learning, demonstrating the effectiveness of ITS in this domain and identifying factors influencing students' intention to continue using these systems . While these studies underline the effectiveness of LLMs and ITS in education, there remains a notable gap in applying these technologies specifically to industrial control education. Our research addresses this gap by fine-tuning a chatbot with industry control-specific data to create a more targeted and specialized educational tool for this field.

Reference original paper, talk about differences.

Expansion and Enhancement of Previous Work

In this project, we built upon the foundational work presented in "Bridging STEM Education and Ubiquitous Learning: A Case Study on Developing a LINE Chatbot with Google's Gemini for Virtual Peer Collaboration." [9] The original paper demonstrated the potential of using a LINE chatbot integrated with Google's Gemini to facilitate virtual peer collaboration in STEM education. While the original study focused on leveraging general educational resources, our approach fine-tuned the chatbot using industry control-specific data drawn from lecture transcripts and PowerPoint presentations provided by our institution. This refinement ensures that the chatbot can deliver highly relevant and specialized content, enhancing its utility for students in specific fields of study. *Additionally, we expanded the chatbot's functionality to better support a diverse array of learning activities, such as interactive quizzes and real-time feedback mechanisms, which were not explored in the initial study. These enhancements not only improved the chatbot's educational value but also demonstrated a more targeted application of AI in a niche academic domain.*

Face-to-face vs. Online

A study from 2021 on Romanian college students [1] found that there’s a greater preference for face-to-face learning compared to online learning. The preference was even greater for students who only experienced online learning (first-year college students during COVID) than for upper-year students who experienced face-to-face learning before the pandemic.

However, it’s important to consider the benefits and the need for online learning. The same study found that students describe the main advantages of online education as being time-saving, the comfort offered by staying home, and the accessibility provided by the online environment.

It’s intuitive to understand how creating courses to fit the needs of students who work, can’t afford to study in another city, or have other conflicts, gives them the opportunity to complete their education at their own pace, allowing them to consider educational tasks deeply and critically. The same three positive advantages were observed in a 2021 study conducted with Polish medical students [2].

EasyPLC and Machine Simulator

Tools like EasyPLC and Machine Simulator [13] facilitate a significant portion of industrial automation training but have limitations in interaction and practical application. These tools often fall short in providing interactive and comprehensive training experiences, particularly in terms of real-time feedback and detailed guidance. Our approach addresses these limitations by integrating a fine-tuned chatbot, which not only offers specialized content based on industry-specific data but also enhances interactivity and student engagement. Our chatbot supports a range of dynamic learning activities that can be supplementary to this approach, providing immediate feedback and facilitating a more immersive and effective educational experience. This innovative integration ensures that students gain both theoretical knowledge and practical skills in a more holistic manner.

Virtual and Augmented Reality Environments and Simulations While enriched virtual and augmented reality environments [14] provide an immersive learning experience, they require substantial resources and may not be accessible to all students. This implies that it does not meet Ubiquitous Learning standards because it is not accessible at any time and anywhere, only if and when the students have access to a VR headset. Additionally, the steep learning curve associated with using VR/AR technology and the potential for technical issues can further hinder their widespread adoption in educational settings.

CAD and MATLAB Simulations

Virtual environments using CAD and MATLAB [15] offer a low-cost alternative for MIMO-level control learning but still lack the interactive and adaptive elements that intelligent tutoring systems can provide. While these tools are valuable for visualizing and modeling complex control systems, they often require significant prior knowledge and expertise to use effectively. Moreover, they are limited in their ability to provide real-time feedback and personalized learning experiences, which are crucial for deep understanding and skill development. In contrast, intelligent tutoring systems can adapt to individual learning paces and styles, offering tailored guidance and support that can enhance the learning process significantly.

Conclusion

There is a notable gap in the literature on the use of machine learning and intelligent tutoring agents (chatbots) specifically for industrial control education, indicating significant opportunity for innovation in this area. Existing research predominantly focuses on traditional methods and virtual simulations, which, while useful, do not fully leverage the potential of advanced AI technologies. By integrating machine learning and intelligent tutoring agents into industrial control education, we can create more adaptive, personalized, and efficient learning environments. These technologies can provide real-time feedback, tailor educational content to individual learning styles, and facilitate continuous learning outside traditional classroom settings. Consequently, there is a substantial opportunity to not only enhance the quality of education but also to make it more accessible and engaging for students, ultimately bridging the gap between theoretical knowledge and practical application in the field of industrial control.

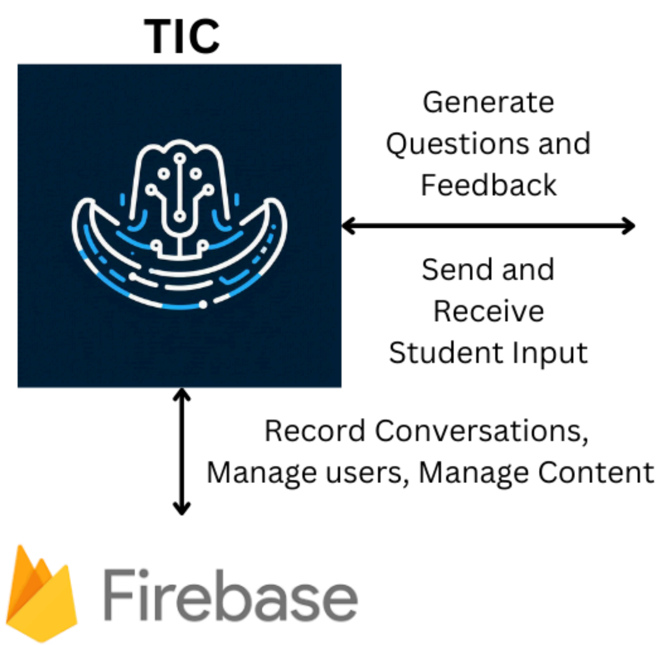
Approach	**Cost**	**Scalability Accessibility**	**Feedback**	**Quality**
AR/VR [14]	High	Mid Low	None	Mid
CAD/MATLAB [15]	Mid	High Mid	None	Mid
EasyPLC [13]	Mid	High Mid	Limited	Mid
Face-to-Face [1]	High	Low Mid	Limited	High

Chatbot Low High High High High

Objectives

The primary aim of our study is to create a chatbot with a user-friendly interface, fine-tuned to address the specific needs of industrial control learning. This chatbot will
harness the power of LLMs to provide an interactive, cost-effective, and scalable learning tool. By integrating this chatbot into existing educational frameworks, we hope to enhance the overall learning process, making industrial control education more accessible and engaging for students and engineers.

Proposed Model



Architecture

The user interface is built using React and Material UI, two popular JavaScript libraries, to create a dynamic and responsive web application. The application runs on a Node.js server and the generative AI capabilities of the chatbot are powered by Google's Gemini API.

AI Model and API

The Gemini API is free (up to 15 requests per minute [16]) which is important for scalability and accessibility. It also provides access to advanced natural language processing and machine learning models. More specifically we used the Gemini 1.5 Flash model, a more lightweight variant designed for efficiency with minimal regression in quality [17]. We fine-tuned the model using domain-specific data. Additionally, we adjusted some parameters, such as temperature, to control the responses and ensure they are appropriate for educational purposes.

Site Hosting

The application will be hosted on a cloud platform such as Amazon Web Services, Azure, or Google Cloud. These cloud services provide scalable infrastructure, ensuring that the chatbot can handle varying loads and maintain high availability. For testing purposes, it will be hosted locally.

Architecture Conclusion

By integrating these technologies, the proposed architecture aims to deliver an efficient and scalable solution that enhances the learning experience for students studying industrial control. We should also consider some limitations, for example the 15 requests per minute, which could change depending on the usage.

Fine Tuning with Domain-Specific Datasets

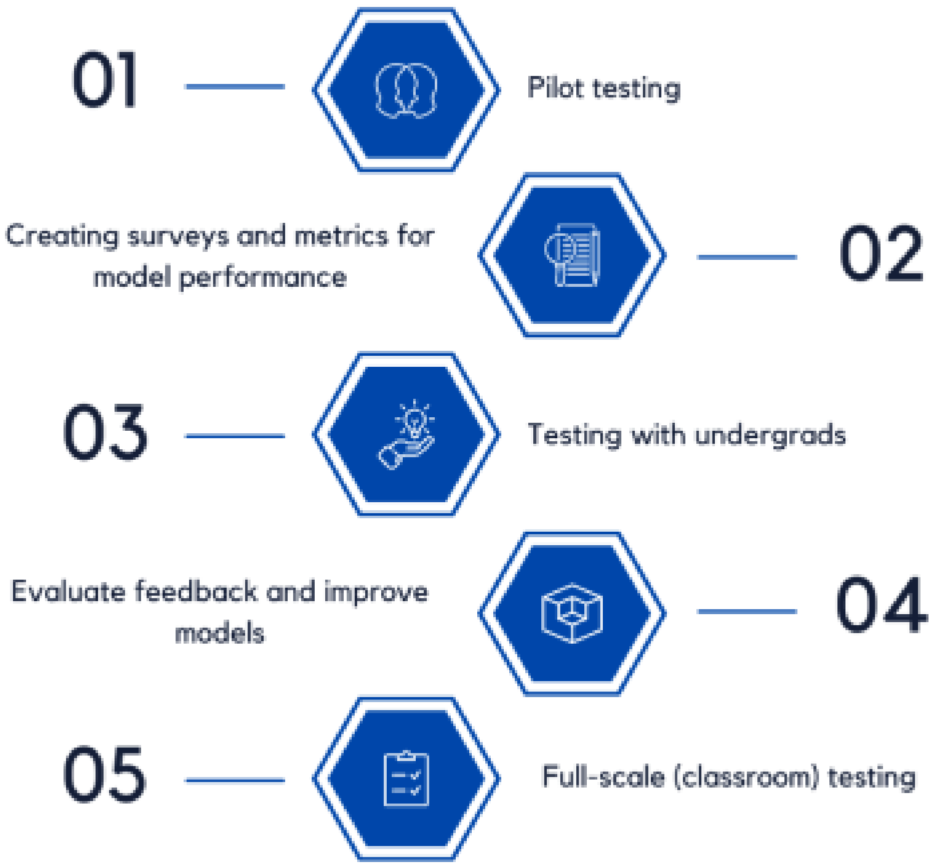
Data Preparation

To prepare the data, we will compile Dr. Hsieh's (professor of Engineering Technology & Industrial Distribution at TAMU) lecture transcripts and PowerPoint slides into a single text format, ensuring the data is standardized and free of errors (inconsistencies and typos can confuse the model during training). Then we can segment the data by topic to improve focus on specific areas within industry control. Finally, we will provide input and output pairs as per Gemini's specifications for fine-tuning [18].

Training Process

Since commercial LLMs are already trained on very large amounts of data, we have to be careful to choose training data that will be effective for our use case. In order to fine tune Gemini, we utilized Google AI Studio, which allows us to directly input images and text while providing a user interface for testing. In our initial fine tuning process, we decided to utilize images due to the intricacies and time constraints of parsing text and creating useful input/output pairings. However, upon completion, we found that the response time for even a reasonably-long prompt exceeded 2 minutes which we believe to be too long. In the future, we plan on fine tuning our model using purely text, parsed from lecture materials, in order to increase efficiency and response time of TIC training. This new fine tuned version of Gemini is trained on 17 lecture pdfs provided by Dr. Hsieh, and includes 350+ screenshots of slides of text. The model is only fine-tuned with the industry control information (which it extracts from the screenshots) we provided and any other responses regarding material that we didn't train it on is a result of the original training of the LLM. Although run time has increased drastically in comparison to the original model (Gemini 1.5 Flash), TIC has provided excellent responses regarding industry control given the data, and we hope to see more improvement with more data and text instead of images.

Experiments



Pilot Testing

To evaluate the readiness of the chatbot for industrial control learning, we conducted several experiments focused on the fine-tuning of the model, optimizing user experience, and assessing functionality and performance. If the model works as planned, it should be able to specialize in industry control, providing detailed and specific answers to questions regarding this subject. Once trained, we tested the chatbot with new industry control-related queries and analyzed how well the chatbot performs. It showed promising results, generating lecture-specific information and very relevant and factually correct responses. We also tested different prompts and parameters on the back-end to ensure the best possible question and feedback generation.

Undergraduate Testing

The next stage of testing will be to provide the ITS to undergrads and review the undergrad's feedback, paying particular attention to user experience and perceived learning effectiveness. If we can optimize the model and provide it to these students, then we can make certain that the model is fine-tuned in the most effective manner and functional for its intended purpose. In order to gather data regarding undergrad opinions, we will create surveys and metrics to evaluate the model and tune it as needed. Then, after providing the resource to as many industrial engineering students as possible, we will test the applicability and accuracy of our model as a resource to help with assignments and learning. Through the surveys and metrics, the data we gather can help us fix any bugs and further fine-tune the model.

Full-Scale Deployment

If the undergraduate testing proves to be successful, then we can move on to deploying the chatbot into real classroom settings to complement the current educational tools for the industrial engineering department. To provide access to all students, we will need to utilize Amazon Web Services (AWS) to host the ITS and maybe further financing to pay for more intensive API requests. Finally, we will evaluate performance by measuring technical metrics like response time and model stability, and also user-centered metrics like student's perceived learning and satisfaction. Ideally we can continue iterating and improving the system for the best experience possible.

Conclusion

There is a notable gap in the literature on the use of machine learning and intelligent tutoring agents (chatbots) specifically for industrial control education, indicating significant opportunity for innovation in this area. Existing research predominantly focuses on traditional methods and virtual simulations, which, while useful, do not fully leverage the potential of advanced AI technologies. By generative AI, more specifically commercially available large language models and their customizability, into industrial control education, we can create more adaptive, personalized, and efficient learning environments. Our ITS can provide real-time feedback that emulates the instructors genuine feedback, tailor educational content to individual learning styles, and facilitate continuous learning outside traditional classroom settings. Consequently, there is a substantial opportunity to not only enhance the quality of education but also to make it more accessible and engaging for students, ultimately expanding ubiquitous learning

opportunities in the field of industrial control.
The integration of LLMs into educational settings is promising but comes with challenges that should be addressed. Concerns about data privacy, bias, and the risk of students becoming too reliant on AI for learning are significant considerations. Ensuring that the ITS operates transparently and ethically while complementing rather than replacing human educators, is essential for maximizing the benefits of this technology. Addressing these challenges will be crucial to fully realize the potential of intelligent tutoring systems in industrial control education.

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