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Development of an AI student assistant in the VR thermal fluids lab and evaluation of its impact on students' learning

Dr. Jessica Ohanian Perez, California State Polytechnic University, Pomona

Jessica Ohanian Perez is an associate professor at California State Polytechnic University, Pomona with a focus on STEM pedagogy. Jessica earned her doctorate in education, teaching, learning, and culture from CGU.

Dr. Yitong Zhao, California State Polytechnic University, Pomona

Dr. Yitong Zhao is an Associated Professor at the Mechanical Engineering Department of Cal Poly Pomona (California State Polytechnic University Pomona). She received her B.S degree majored in Micro-Electrical-Mechanical System (MEMS) from Tsinghua University in China. She received her Ph.D. degree in Bioengineering from UCLA under the guidance of Dr. Chih-Ming Ho. Since joining Cal Poly Pomona, she has been focusing on STEM education with the assistance of technology to tackle the challenge of the new age of education. Her current focus is in utilizing virtual reality (VR)/augmented reality (AR) and mixed reality (MR) technology to improve the effectiveness of engineering education. Her other interests include autonomous vehicle and data science.

Prof. Juliana Lynn Fuqua, Cal Poly Pomona

Juliana Fuqua, Ph.D., is an Associate Professor in the Department of Psychology and Sociology at California State University Polytechnic, Pomona who completed her doctoral degree at the University of California, Irvine. Dr. Fuquaâ€™s dissertation at the

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Abstract

The COVID-19 pandemic illuminated challenges with student experience with laboratory instruction. It caused the field to rethink how we engage students. This, in conjunction with tight spaces and a growing student population, has led to the need for more inventiveness. This project explores the efficacy of an enhancement, the incorporation of an artificial intelligence (AI) assistant in a thermal fluid laboratory experiment. The virtual reality lab was designed by student assistants and the principal investigator, and the AI was powered by Generative Pretrained Transformer (GPT) technology. The goal of the VR is to increase student participation in the lab. The goal of the AI is to bridge holes between theoretical knowledge and engineering practice. The lab experiment was implemented in a senior-level mechanical engineering course mid-spring semester 2024. This topic was traditionally eliminated from the course due to the costs associated with the experiment. The student groups performed the experiment in three different modalities: traditional, with virtual reality only, and with virtual reality with an artificial intelligence assistant. Students reported that while it made a good educational experience, the VR and AI are not perfect. Reports of lack of haptics and long-winded responses from the AI assistant made the moderate gains seem to pale in comparison to the benefit the VR provided. Students reported appreciating that VR allowed for engaging more students and providing access to the lab outside of normal class times. This allowed for reworking the lab if a student was struggling, additional study time, and extended engagement with the topic.

Introduction and Literature

Though the COVID-19 pandemic created unprecedented challenges to education, particularly in STEM disciplines where hands-on experience is crucial for students to comprehend complex concepts, new resources were also made available. Previous studies have demonstrated the efficacy of virtual reality in providing opportunities for student participation [1]. California State Polytechnic University Pomona has invested in state-of-the-art Virtual Reality (VR) laboratory for thermal fluids. This project explores the efficacy of an enhancement, the incorporation of an Artificial Intelligence (AI) assistant. The AI was created so it can assist students in bridging gaps between theoretical understandings and engineering practice, while also expanding access to a wider range of students. In practice, we are evaluating for student performance, student understanding, and student experience.

Recent data from 2020-2023 reveals a concerning downward trend in the passing rates for prerequisite courses for the class. Thermodynamics (ME 3011) and Fluid mechanics (ME 3111). The rate of passing for thermodynamics has fallen from 87% to 69%. The passing rate for fluid mechanics has decreased from 96% to 81%. In addition, an equity gap has widened between underrepresented minorities (URM) and non-URM, with the difference in course grades increasing in thermodynamics from a 0.12 course grade gap to 0.28. In fluids the gap went from a 0.14 course grade gap in 2020 to 0.18. This means students are passing the course at a lesser rate and that URM students are trailing behind their non-URM counterparts scoring an average of 0.2 GPA grade points lower. For the course in question, the grade gap has widened from 0.13 to 0.29. Some data points attribute the decline to the learning loss experienced during the COVID19 pandemic. However, there have also been changes to pre-requisites, and material covered. This is further compounded by limited resources, and aging equipment. To combat these issues, the Mechanical Engineering department at Cal Poly Pomona developed a VR lab that contained 6 different thermal fluids experiments. The VR lab provides an immersive experience that removes some of the challenges of traditional lab settings such as limited hands-on time, limited space, and worn-out equipment. Furthermore, the impact on the quality of learning is also apparent in the sub-sequencing course. While the VR labs address some of the issues facing students and faculty, there seems to still be a gap in understanding and ability to apply concepts and topics. Can AI assist in closing equity gaps, and improve student overall understanding and performance?

Virtual Reality and Engineering Education

Virtual reality (VR) labs have emerged as a way to increase access and participation and have proven to have potential benefits to students [2,3,4]. It has also been shown that VR education improves academic performance and increases motivation as well as enjoyment of class material [5,6]. Studies have shown that the use of VR in education also improves comprehension of abstract concepts and improves long-term retention [7,1,8,9].

More importantly, VR has the potential to increase equitable instruction and learning for students. Not only students reporting a higher level of enjoyment in learning, but also an increased knowledge of the subject when pressure of a traditional learning is decreased by the additional support of VR [7]. It has also been found that increasing the use of VR allows students more flexibility in attendance and the ability to balance demands of the home and school [10]. While the benefits of VR instruction has been studied in a limited way, the use of AI coupled with VR has yet to be explored.

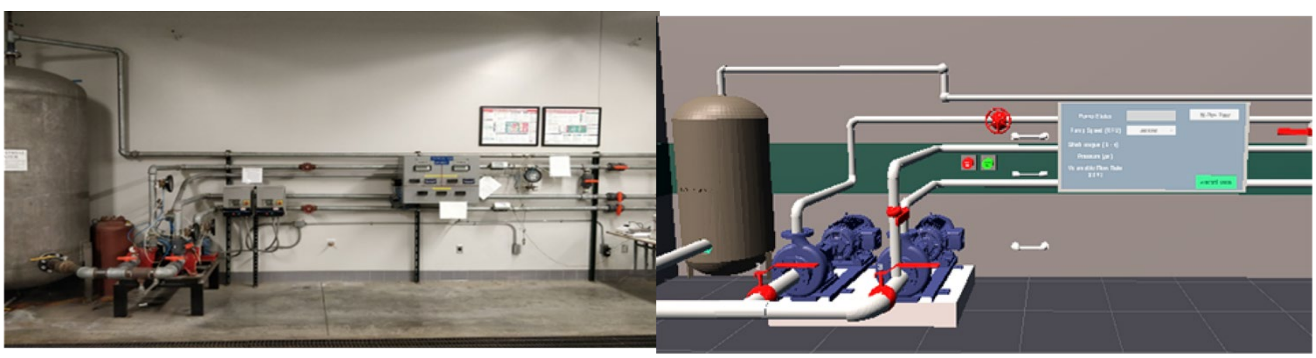
Implementation

Our originally developed VR lab presents a promising solution to address challenges such as limited hands-on time, insufficient space, scheduled lab time, worn-out equipment, and lack of maintenance. However, the recent pandemic has brought new challenges to the traditional mode of learning, including a range of student behavioral changes such as a greater dependence on unverified online resources, an increase in the diversity of learning styles, a desire for prompt feedback, and an inability to participate in in-person interactions due to various reasons. To address these challenges, we propose to enhance our existing VR lab by leveraging the latest AI technology to offer students a more individualized and immersive learning experience. After this pilot test, the intention is to expand the use of VR and AI so that students can “check them out” from the department and have access at off times allowing for review and independent work. The AI assistant can, in theory, provide immediate feedback and answers to students' questions related to the subjects with accuracy, as the AI assistant’s responses will be overseen by faculty in the subject area. This information provided to the students, which could further improve their understanding of the concepts being taught. The primary goal of incorporating this feature into our existing VR lab is to provide students with a more interactive and personalized learning experience. Pictures 1 and 2 below show the students using the VR and AI technology in class.

Picture 1 and 2 Students using the VR and AI capabilities in class

For each course using a VR lab, the AI assistant is connected to the Generative Pre-trained Transformer (GPT) language model via Application Programming Interfaces (APIs) and acts as a non-player character (NPC) in Unity. The AI provides personalized guidance, answers students' questions, and makes course faculty aware of specific skill and knowledge gaps. This pilot study aims to evaluate the effectiveness of the AI-assisted VR lab in improving students' experience, understandings, and performance in thermodynamics and fluid mechanics courses, as well as bridging the equity gap between underrepresented minority (URM) and non-URM students. Below in Picture 3, the real-world lab space is shown next to the virtual lab space.

Picture 3 the actual and virtual lab spaces



(a) (b)

Evaluation

To evaluate the impact and effectiveness of the proposed technology, a mixed methods approach combining experimental data, survey research, and qualitative data will be used [10,11]. Specifically, to test the effectiveness of the AI-assisted VR lab, the evaluation was carried out in the ME3131L thermal fluids lab course. This course was selected due to its suitability for conducting experiments and multiple sections of the course are available for control purposes. We set up three groups: one experimental group where the students have access to the AI-assisted VR lab, one experimental group where students have access to the VR lab without the AI assistant, and one control group that does not have access to either version of the VR lab (control). To maintain a strong evaluation methodology and decrease the impact of external factors, six sections of the course were selected for the study- two instructors each taught three sections. Neither of these instructors were the instructor who developed the VR or AI technology for the course. There was one of each treatment group for each instructor. We conducted surveys, focus groups, in-class observations, and evaluate grades to gather feedback on the intuitiveness, functionality, and potential resourcefulness of the updated VR lab in an educational setting. Students were aware why the outside students were in the room during the observation. The notion that it was peers observing and collecting the data allowed students to answer more freely. The methodology has been proved effective in online learning evaluations. Due to the limitations on the project and the timing of the lab activity, satisfaction with the technology was evaluated. The next phase of the study will measure student learning.

Participants

Participants were 97 mechanical engineering students enrolled in one of six class sections of a course (ME 3131L) who attended class during the week of March 2024. The sections were taught by two instructors, each of whom taught the class during one week in one of three ways: a VR+AI format, a VR-only format, and a typical-lab control format (the usual physical lab). The class session was attended by approximately 16 students per session, or more than 95% of the class enrollment). Table 1 below shows the number of participants by treatment and table 2 shows the breakdown of gender by treatment.

Table 1: Participant count by treatment

	VR and AI	VR only	Control (no enhancement)
Professor 1	18	20	11
Professor 2	6	15	10

Table 2: Participant count by gender

	Male	Female	Decline to state
VR/AI	19	5	
VR only	29	6	
Control	12	8	1

Survey

A pre-test survey was conducted early in the semester and post-test survey was conducted immediately after the lab was completed. In the pre-survey demographic data as well as familiarity with video games and involvement of students including on campus and off campus responsibilities was collected. Demographic data suggests that students reported a variety of obligations outside of school including caring for family with disabilities, caring for siblings, and work, along with school related commitments such as internships and engineering clubs. These outside commitments are more prevalent with students who have reported being first generation college students, and student who are female. In school activities were more commonly reported by male students.

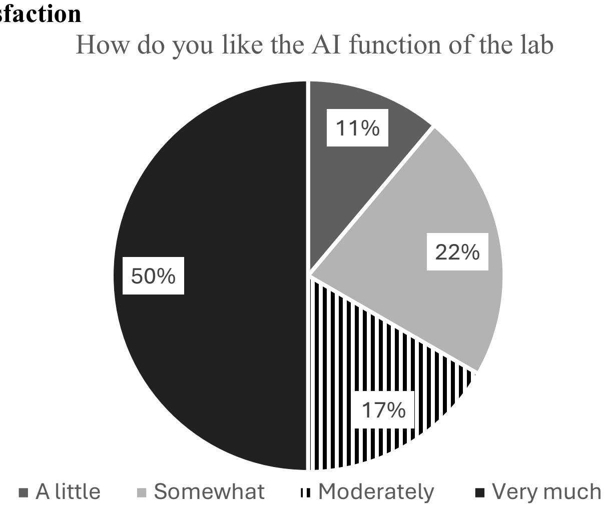
On the post survey, students were asked questions about how well they like VR, AI and their overall satisfaction with the lab. They were invited to participate in focus groups after completing the pre-survey and the lab. The focus group immediately following the lab, was able to get specific details about the VR and AI functionality of the lab and student satisfaction. The questions were intentionally open-ended to give students the chance to speak on their experience in the lab. The team also observed the interaction in the class of students and was able to compare how much students engaged and which students were engaging and in which roles. Focus group were conducted immediately after the lab.

Findings

Quantitative Data

Students expressed to us that instructor encouragement influenced their interest in using AI. This was a five-point Likert scale 1: Not at all to 5: Very much. Of those who had access to AI for their labs, three quarters were at least moderately satisfied, and 50% reported liking the AI function very much. No one reported disliking the AI entirely. Figure 1 below shows these results.

Figure 1: AI function satisfaction



Qualitative Focus Group Findings

Several themes were evident based on the data that was collected.

Artificial Intelligence (AI)

The AI assistant is a great tool in theory, but it needs further development to be effective. The assistant was somewhat beneficial in guiding students through the lab (e.g., a few students felt it helped at least a few times in the labs). However, the AI was not very beneficial in explaining the lab concepts. There were several difficulties with the AI. First, at times, the information was distracting (or inaccurate) and irrelevant to the lab they were doing, despite the fact the AI was programmed for the specific lab. When students were doing a step, they would ask a question about what to do next, and it didn't tell them what to do next. After students refined their questions to be a more precise statement, the AI would give them the correct answer. It was a learning process for the students to guide them. This could be due to the fact the AI is geared towards conceptual understanding.

There are a few things that impacted student experience with the AI:

- Enthusiasm of the instructor- One instructor named the AI and was enthusiastic about it. As a result, students were more excited. One unexpected observation was that students had drastically different attitudinal and emotional reactions to the VR+AI. One class section really seemed to dislike it, feeling it was not helpful. The other class section had fun and enjoyed trying the technology. The cause might the instructor. In the first section the instructor introduced it in a bland way. In contrast, the second instruction shared contagious enthusiasm. The instructor seemed to enjoy talking with students about the AI, and they students did too. They all talked about the AI like it was a person, named "Sassy".
- The level of feedback needed by the student. The AI is good for basic clarification questions but the AI was limited in deeper questions or questions that required higher order thinking or conceptual understanding.
- The length of the answer. The AI gave too long of an answer. Our AI (Sassy) gave particularly long answers, including a 5-minute-long answer...which is frustrating to students. They asked a simple question and wanted a simple answer. When that happened, they wanted to be able to turn off the AI temporarily or permanently. They coped by totally muting it. A better solution would be for the AI to have a feature like Alexa or Siri in which users can easily say "hey, stop". That's essential, according to students.
- How the AI was responding to the surrounding speech. AI occasionally responded to not direct questions so if the student was talking through the lab as they completed the assignment, the AI would respond to a question that was not asked.
- Students felt that the AI was trained on ChatGPT. Students were asking history questions to it, and it was answering with somewhat relevant answers. For example, famous historical figures questions seemed accurate. It was not clear to students where the data was coming from.
- The microphone was always on. Some students wondered if this might have interfered with the AI's learning. The room was very loud with groups very close together.

Virtual Reality (VR)

The VR portion of the lab has various benefits for the physical lab space and students. The use of VR allows shared spaces and lab equipment to have more flexibility in scheduling. The VR portion of the lab has numerous benefits for the physical plant and students. Students can work in their timelines. If a student has access to a VR lab outside of the scheduled class time, they can rework labs to review or complete work missed due to absence. Students also appreciated that the program automatically does math for you as you do the lab. Typically, labs require students to record data in a lab book. This VR feature saved them a lot of time and effort and ensured there were no errors in calculation.

Some of the positive findings for the VR (both with and without the AI assistant) included:

- Female students have found themselves relegated to notetaker or observer during labs, unless in an all-female team. AI combined with VR offers the opportunity for supplemental access with support for students (regardless of gender) who may have faced challenges with hands on labs. Female students reported being more involved in the lab with technology enhancement.
- Increases accessibility for students who might have trouble accessing it. Usually, only a few students have the opportunity to use physical lab equipment because labs are usually group-based, and only one person per group gets to touch and use the equipment. Not true for VR. Each student gets to use the equipment. Also, students who cannot come to campus or have other relevant challenges and responsibilities (illness, disability, staying home with a sick child or family member) could use the Technology as replacement or a supplement.
- Furthermore, students can go at their own pace as they stop and reflect on what they are doing, which can enhance their learning. They can try things, and think through what they are doing, in a fully engaged way. This is particularly important for learning.

There were concerns brought to light with the use of VR:

- The lab experiment is gamified so there is no possibility of making mistakes and adjusting like there is in an actual lab setting. Students expressed an interest to trouble shoot in the VR as it would be more realistic. One student felt it was more like a tutorial just 'brainlessly' following steps or mimicking steps rather than truly learning how to do it and learning the course content. They said they didn't think they could repeat or use the concepts again later.

- The physical indicators that the machinery has are not present in the VR. For example, students discussed how do you know when turning a valve, it is completely open? This could be remedied with haptic feedback on the device.

- Some students reported a level of motion sickness and cannot do the lab for very long.

Drawbacks of technology assisted lab experiences- Things to consider

- Failing and making mistakes is an important part of typical lab experience. The technology isn't designed to allow them to easily make mistakes and learn from it. For example, if you are turning a pipe and you need to know how to connect two pipes, you might need real equipment to ensure you know how to do it.
- In addition, students feel it is important to gain experience in teams, and they don't get to practice their teamwork skills with the current VR.
- Dependency on language. The AI assistant for the lab was programmed in English, this could be limiting for students who are not native English speakers and have differing language patterns.
- The lab came across as a game rather than a way to learn the lab content. It was "gamified" in their view. So, they felt they weren't learning as deeply. One student felt it was more like a tutorial just 'brainlessly' following steps or mimicking steps rather than truly learning how to do it and learning the course content. They said they didn't think they could repeat or use the concepts again later. The AI could direct students to resources outside of the lab materials to ground the experience in a less virtual or theoretical environment.

Conclusion

The integration of AI and VR in laboratory experiences presents both significant opportunities and challenges. AI, while a promising tool for guiding students through lab activities, still requires further development to meet educational needs effectively. It was found to be helpful in providing basic clarifications but struggled with complex queries, often offering overly detailed responses or irrelevant information. The enthusiasm of instructors played a key role in shaping students' engagement, with those who were more enthusiastic fostering a positive reception toward the technology. However, the AI's limitations in terms of its interactivity and responsiveness to student needs, as well as its tendency to offer distracting or imprecise information, highlight areas for improvement.

Similarly, the VR component of the lab showed promise in enhancing accessibility, especially for female students and those with scheduling or physical challenges, by allowing individual engagement and flexible learning. The ability to review and complete lab work outside class hours was a significant advantage, along with the elimination of human error in calculations. However, the gamified nature of the VR experience and lack of realistic, hands-on problem-solving left some students feeling that the experience was too disconnected from actual lab work. The absence of haptic feedback and the inability to make mistakes and learn from them, a key element of traditional lab settings, raised concerns about the authenticity of the learning process.

The use of VR and AI bridges some very critical gaps in resources, for both the university and students, and provides students the ability to work on topics at an individualized pace. The technology also allows each student to have a chance to work the experiment (something that is often lost in group traditional lab settings). These factors increase the equity of the experience for students to hopefully combat declining pass rates for the courses. Even though this is a pilot study, the benefits of the VR and AI lab prove the need for further modification of the technology and expansion for student use.

Overall, while both AI and VR have the potential to transform lab-based education by increasing accessibility and enhancing individualized learning, careful attention must be paid to refining these technologies. Incorporating more realistic, error-tolerant features in VR, improving AI's contextual understanding, and fostering more interactive, engaging learning environments will be essential for maximizing their educational impact and make the best use of limited space and resources as enrollment grows but our campus facilities do not.

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