A Virtual Lab of Matrix-Assisted Laser Desorption Ionization MALDI-TOF Protocols for Microbiology Students

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Abstract.
This study is a practical way of teaching software engineering and microbiology in a virtual setting, which is beneficial during natural calamities, including the recent pandemic. This project details how the software engineering students developed a virtual lab for the microbiology students that started as a class project. The benefit of creating the project for the software engineering students was that it helped to develop their soft skills and the details of collecting requirements. Similarly, it allowed the microbiology students to collaborate with software engineering students to educate them on the protocol and eventually practice the MATDI-TOF experiment before they do it in their labs. Input from microbiology students seems crucial in ensuring that the virtual lab accurately reflects the real-world lab environment and meets the needs of those conducting experiments. This study explains how students learned to communicate in developing real-world software as a class project. The study exemplifies how technology can bridge the gap between theoretical knowledge and practical skills.

Keywords: Virtual Lab, Software Engineering, Microbiology, Virtual Reality

1 Introduction

This study investigates a university setting where almost half of the undergraduates are non-traditional students. These students may have work and family obligations that leave them little free time outside regularly scheduled classrooms. The virtual lab develops flexible learning strategies to make the research opportunities productive for diverse, non-traditional students. Virtual laboratory simulations (VLS) can supplement traditional teaching laboratories and allow students to learn at a distance at their own pace. These systems can also help students continue their learning of non-cognitive science skills during campus disruption, like the recent pandemic.
The evolution of traditional microbiology education into a cutting-edge Virtual Lab for Microbiology involved transforming a pre-existing PC-based application into an immersive VR experience. This section delves into the development process, challenges encountered, and the iterative improvements made based on valuable feedback.
This project aims to develop a virtual lab to teach students microbiology laboratory techniques remotely. VL was essential during this pandemic, but these simulations will supplement traditional laboratory training exercises and facilitate sharing protocols between institutions. This project will be an innovative technique of interdisciplinary teaching that will mimic a real-world situation for microbiology and software

engineering. This will encourage and supplement microbiology students to learn and practice the lab work by doing virtual lab work in an informal setting.

2 Background

2.1 Literature Review

VLS range from immersive to observational models. Immersive models involve 3D simulations; however, this immersive approach doesn't necessarily improve student learning [1, 2], and broad implementation would require students to acquire specialized equipment or use on-campus facilities. In the observational model, students watch videos showing step-by-step protocols. This video approach effectively improves cognitive skills [3]; however, there is little evidence that the observational models improve manual (non-cognitive) laboratory skills. PC-based laboratory simulators teach manual laboratory skills like a flight simulator trains pilots and appear effective in preparing microbiology students for laboratory work [4]. Labster (Denmark) and other vendors have developed laboratory simulations; however, the company controls the content, limiting the curriculum available to instructors. Further, many students and universities need help to afford to pay for these commercial products.

Collaborate with software engineering (SE) and microbiology (MB) students to develop VLS of MALDI-TOF protocols. PC-based VLSs teach manual laboratory skills the way a flight simulator trains pilots. These simulators appear effective in preparing microbiology students for laboratory work [5]

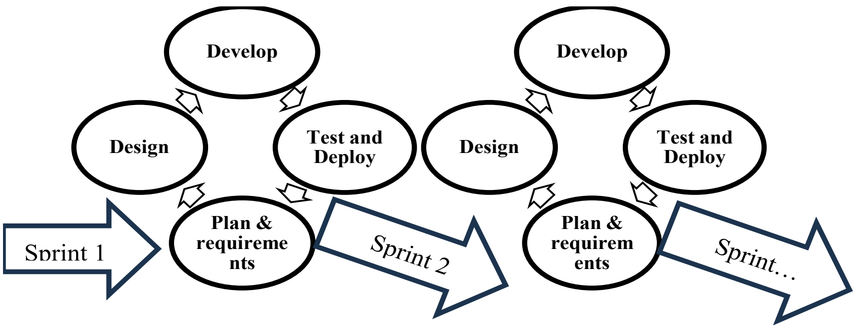

Fig. 1. The Iterative Process how each component was developed, starting from the core element (Agile process)

2.2 The Goal

The goal was to help SE students understand software development, teamwork, and communication with other domain experts and users. A collaboration between SE and MB students to develop a virtual lab of MALDI-TOF protocols helps with the goal.

These simulators appear effective in preparing microbiology students for laboratory work.

This project is an innovative interdisciplinary teaching technique miming a real-world situation for both SE and MD students. It will advance the SE field by integrating two methods, i.e., agile (fig.1, which had seven sprints) and design thinking frameworks, in developing software [5]. The VR-lab will encourage and supplement microbiology students to learn and practice the lab work by doing virtual lab work in an informal setting.

3 Laptop Version of the MALDI-TOF Virtual Lab

This initial application had limitations: relying on keyboard inputs, lacking hands-on experiments, and resembling a quiz rather than an interactive learning experience. The virtual lab(VL) concept started during COVID-19 in April 2020 when microbiology students could not come to the lab to do lab work.
The idea of building it in-house was because buying a commercially made software application was expensive both for the student and the university. Although, that would have been perfect software. On the other hand, not every experiment has the same protocol. Every professor or instructor teaches an experiment in various ways [6]. Hence, it is reasonable to develop the software on campus.

This VL was first built using Unity. The VL then had a mouse and keyboard. Students were able to install it on their laptops. It was not three-dimensional as in virtual reality, but it was a version that students could still practice the experiment using their laptops and understand the protocol. The VR-Lab was assigned as a class project to a team of four.

Since this started during the Pandemic in September 2020, requirements were collected by either joining the Zoom session or reviewing the video recording from the instructor. Students interested in doing something using Unity were teamed into one group, and they started working on it. A prototype of the software was developed by the end of the semester. In the next semester, another team of students continued to work on the project. During this semester, the team was asked to add a new feature to the product. A research assistant started converting the prototype. During the semester, students developed new features that were later integrated into the product. Some features added in this version were a virtual lab instructor, a demo option by the lab instructor, a whiteboard with instructions, and a knowledge test. Features that were not added were the lab book.

Another student researcher working on this one was a microbiology student. The MB students could be guided with their domain knowledge about what was right because all the others developing were computer science/software engineering students. Thus, it went through several iterations, leading to the beta version. Microbiology students used the beta version before their actual lab experiment.

Microbiology students pointed out some significant changes that were required in beta versions are mentioned here: The robot lab instructor had to have a lab coat, the shoes of the lab instructor were not appropriate, and the lab instructor had to wear protective glasses during the demonstration. SE students learned the importance of collecting detailed requirements. A screenshot of the beta version of this software is shown in Fig. 2.

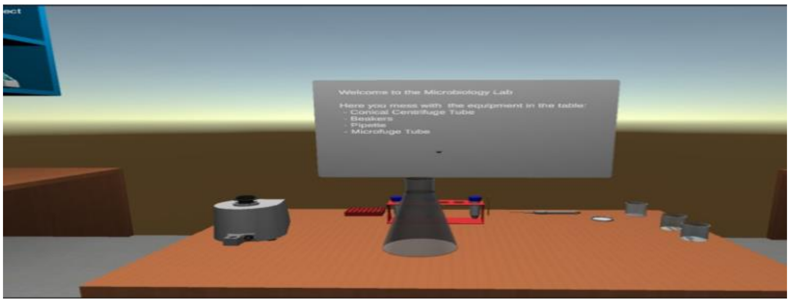

Fig. 2. Screenshot of virtual lab simulation developed to prepare students to implement the ethanol/formic acid extraction protocol. This VLS was encoded in Unity (2020.1.5) and C#.

4 Virtual Reality Version of the MALDI-TOF Virtual Lab

4.1 Introduction

In response to the favorable reception of the initial version, our aim was to elevate the project's immersive qualities. To achieve this, we sought to transform the project from a desktop application into a Virtual Reality (VR) application compatible with Oculus Quest devices. This strategic shift was prompted by valuable feedback from students and professors who had experienced the first version of the project. Rather than starting from scratch, our objective was to convert the existing application into a VR format, harnessing assets from the original version.

During the development process, it became evident that a restructuring of the application code was imperative to seamlessly transition it into a Virtual Reality application. This decision was driven by a desire to enhance the overall user experience and cater to the specific needs and preferences expressed by our user base.

4.2 Development Journey

The objective of this version was to transition from a PC-based application to a VR environment. However, the process faced initial setbacks due to resource limitations, including the absence of essential equipment such as a gaming PC, Unity software, and an Oculus Quest. Logistic challenges, such as issues with hand tracking and hardware malfunctions, further prolonged the development phase.

The first version of the VR application had to use controllers due to these initial technical constraints. We integrated the lab environment from the previous application to expedite development, maintaining user familiarity. The product initially occurred in Unity version 2021.3.16f1, later transitioning to Unity 2022.3.2f1.

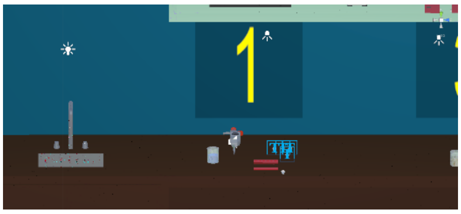

Fig. 3. The Water Station (Station 1) marks the inception of experiments. It features a beaker containing water and essential apparatus such as a pipette, pipette tips, and test tubes. The pipette, a crucial tool in the experimental process, allows users to extract a predetermined quantity of water and transfer it into designated test tubes. The pipette tips are designed for single

Fig. 4. At the Bacteria Station (Station 2), a disk container harboring a diverse array of bacterial samples is provided. This station also incorporates a loop mechanism, enabling users to introduce bacteria into the experimental solution

the Virtual Reality (VR) Lab, meticulously crafted for seamless use on any Oculus Quest device and developed utilizing

Fig. 5. Moving on to the Ethanol Station (Station 3), students encounter a dedicated beaker containing ethanol. The station is equipped with a pipette, enabling users to extract a precise amount of ethanol from the beaker into smaller test tubes, crucial for experiment protocols.

Fig. 6. Vortex Machine Station (Station 5) introduces a vortex machine, a vital apparatus for specific experimental processes. A user-friendly switch mechanism allows students to activate and deactivate the vortex as needed, enhancing the overall experiential learning process.

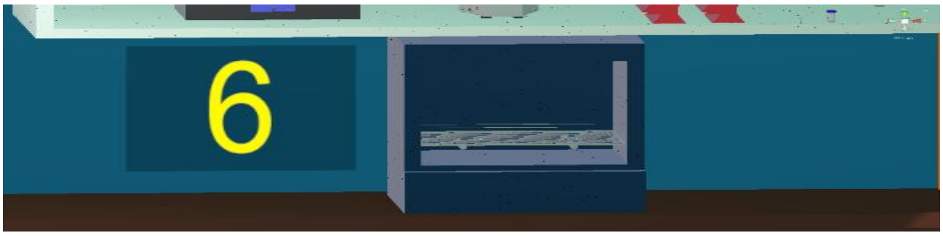

Fig. 7. The Refrigerator Station (Station 6) houses a virtual refrigerator, serving as a valuable resource for students when the need arises to cool a particular solution as part of experimental procedures.

Unity 3D, represents an immersive replication of the microbiology laboratory. Comprising six intricately designed stations, each is pivotal in facilitating a comprehensive and hands-on learning experience. Designed to utilize Quest controllers, each control is meticulously mapped using Unity Input Manager, ensuring precise and intuitive interaction within the virtual environment. This thoughtful integration enhances the user experience, allowing students to seamlessly navigate and engage with the VR Lab, fostering a dynamic and effective learning environment for microbiology experiments.

Figure 3 to Figure 7 shows various stations present in the VR application. Each station is meticulously crafted to replicate the physical attributes of a microbiology lab and incorporates interactive elements that amplify the educational experience. This detailed and immersive design ensures that students can seamlessly navigate and engage with the VR Lab, fostering a dynamic and effective learning environment for microbiology experiments.

Additionally, a Virtual Lab Assistant has been integrated into the VR Lab environment to enhance the overall learning experience. This digital guide is designed to provide step-by-step instructions, offering insightful guidance to students navigating through the experiment procedures. The Virtual Lab Assistant plays a pivotal role in ensuring the correctness of each student's action, promptly identifying and correcting any deviations from the prescribed protocol. Through interactive prompts and real-time feedback, the assistant not only assists students in understanding the intricacies of the experiment but also serves as a valuable tool for reinforcing proper laboratory techniques. This innovative feature adds an element of personalized guidance, creating a supportive and immersive learning environment within the virtual microbiology laboratory.

For the controls in the VR Lab, user interaction is seamlessly facilitated through intuitive controls mapped to the Oculus Quest controllers. The left analog stick allows users to navigate the virtual environment, providing fluid and responsive movement. Meanwhile, the right analog stick enables users to look around and explore the intricacies of the laboratory freely. Essential for manipulating experiment parameters, the 'A' button is designated to increase values, while the 'B' button serves to decrease them, ensuring precise adjustments during the hands-on learning experience. The functionality of holding and interacting with objects, such as the refrigerator handle or vortex switch, is seamlessly executed using the right and left grip buttons. The right trigger is employed to utilize the pipette, offering precise control and responsiveness. On the other hand, the left trigger is designated for the critical function of ejecting the pipette tip, enhancing the overall realism and functionality of the virtual microbiology laboratory experience. These carefully mapped controls mirror real-world actions and contribute to an immersive and educational journey within the VR Lab.

4.3 Experiment Protocol

In adherence to the official procedure, the first step involves meticulously labeling the frosted side of each Eppendorf microfuge tube with assigned positions, denoted as B1, B2, and so forth, alongside the researcher's initials. Following this, 300 µL of water is methodically added to each tube at the designated Water Station. Moving to the next phase, a large, singular colony of microorganisms is carefully transferred to the tube, with potential variations based on the microorganism's size, emphasizing the selection of isolated colonies. This step involves labeling the tube's top with its position (e.g., B01) and the researcher's initials for clear identification. Subsequently, a thorough vortex is executed to ensure homogeneity within the solution. The procedure advances to the Ethanol Station, where 900 μL of ethanol is meticulously added to the tube, followed by another round of thorough vertexing. Placing the tube in its designated position within a 96-well microtube rack (e.g., B1 in B1), researchers are presented with the option to either store the prepared sample at 4 ºC for a period of up to two weeks or proceed with the subsequent phases of the experiment. This comprehensive and sequential approach ensures precision and adherence to the established microbiology experiment protocol.

The primary objective of our VR simulation is to replicate the Formic Acid/Ethanol Tube Extraction (TE) Method, a crucial laboratory technique employed in microbiology. The underlying principle of this experiment revolves around addressing the challenge posed by microorganisms with naturally thick cell walls, such as yeast, and older isolates like Staphylococcus sp. and Corynebacteria sp., which may develop thicker cell walls over time. The necessity arises to effectively break down these robust cell walls and separate ribosomal proteins before proceeding to spectra analysis. In cases where the conventional ethanol-formic acid (eDT) procedure fails to yield the desired scores, the TE procedure becomes a vital last resort. The VR simulation is an innovative educational tool that allows students to practice this specialized laboratory method hands-on. It not only offers a safe and accessible learning environment but also provides a dynamic platform for students to familiarize themselves with the intricate steps of the TE method, promoting a comprehensive understanding of microbiological techniques.

During the development phase, one of the primary challenges revolved around devising controls for each device incorporated into the virtual laboratory setting. Devices with relatively simple functionalities, such as the vortex with only one switch, posed minimal developmental hurdles. However, more complex instruments like the pipette, which entails many actions a student is expected to perform, presented a considerably more significant challenge. The intricacies of the pipette's functions made developing its controller notably more complicated in the current application version. Moreover, devices that demanded heightened precision, such as the pipette, required a substantial investment of time in the development process. Navigating these challenges was essential to ensuring each laboratory instrument's realistic and practical integration within the virtual environment, contributing to an authentic and educational user experience.

5 Conclusions, Feedback, and Future Work

Feedback from students and other stakeholders, given anonymously, played a crucial role in enhancing our system. Users pointed out a learning curve, stressed the importance of precise instructions, and suggested additional hygiene considerations. The feedback also highlighted challenges such as speech clarity, navigation issues, and understanding instructions. Specific concerns included difficulty recognizing pipette tasks, the need for pop-ups, and suggestions for better lighting. The administration recommended starting with a familiar VR experience like Beat Saber to ease students into the virtual environment. Additionally, as MB students collaborate with SE students to

communicate their requirements, they foster team building and gain insights into real-world situations.
Two main challenges surfaced: SE students faced time constraints in developing the VR Lab for the experiment, and testing the lab involved both SE and MB students. With only two sets of equipment available in the library, students had to sign up for their turn to practice or test the system.
In response to the received feedback, future iterations of the VR application will prioritize transitioning from controllers to a more intuitive hand interaction system. These improvements aim to enhance instruction clarity, address hygiene concerns, and refine the overall learning experience. This iterative approach ensures the evolution of the Virtual Lab for Microbiology into a practical and user-friendly educational tool. Another upcoming project involves developing a VR lab for a Deoxyribonucleic acid (DNA) prep protocol for Polymerase chain reaction (PCR) tests, with the requirements collection for this project currently underway.

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