Work-in-Progress—Titration Experiment: Virtual Reality Chemistry Lab with Haptic Burette

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***Abstract*—With the ever-expanding development of affordable and available virtual reality headsets, there is a great opportunity for improving learning outcomes through virtual learning. Towards a future of online chemistry education, we present a titration experiment with a corresponding physical haptic burette to embed the physical sensations of labwork inside virtual reality learning for broad access. Our work in progress paper investigates how tactile interactions into fully immersive worlds can improve learning outcomes in multi-modal manners and lead to better understanding and retention of key chemistry concepts, e.g., titration principles.**

***Index Terms*—chemistry, virtual reality, titration, haptics**

I. Introduction

Virtual reality (VR) immerses users in virtual experiences, which can be used to immerse students in educational curriculum. In online learning contexts, VR can grant students the ability to virtually access resources and situations not traditionally at their disposal, including large, expensive, and hazardous equipment, chemicals, and experiments. As VR devices have become more affordable and accessible, we envision a future where affordable and accessible virtual reality devices can transform the future of remote learning.

Through this project, our goal is to enhance online chemistry education through developing a virtual reality experience around titration experimentation. We developed an acid-base titration experience that leverages two affordances of VR that have been recognized in the literature: presence and gesture [1]. Students can observe the fluid interactions and color change characteristic of a titration, and also determine the volume of liquid dispensed through reading the meniscus of the liquid inside of the virtual burette. Through a 3d-printed electronic apparatus, students also have control over a physical haptic burette, which manipulates the corresponding virtual burette in virtual reality.

Our lab combines visually compelling fluid interactions with the tactile sensation of a haptic burette for a convincing titration experience. We hypothesize that this lab will improve learning of the chemical principles underlying decision-making involved in performing an acid-base titration.

II. Related Works

We are interested in maximizing the potential of online learning media for chemistry laboratory education through exploiting the affordances of VR. VR can provide dynamic and compelling learning experiences where current online learning curricula fall short. Most online learning experiences for chemistry are constrained to interactions with a mouse and keyboard, and lack tactile laboratory feedback.

There have been efforts to study the use of virtual worlds for virtual learning, including the use of Second Life (SL) for visualizing chemistry concepts [2]. Two studies found that when high school and college students performed chemistry experiments in SL, their learning outcomes were similar to when they performed the real equivalents of these experiments [2], [3]. Even so, these experiences are limited to a 2D screen, and all interactions with virtual apparatuses are strictly via mouse and keyboard. There has been work to incorporate more tactile experiences with online chemistry through a Wii remote [4]; however, these experiments still have a 2D display interface and fail to show rich fluid interactions from freely positioned perspectives.

Research suggests that VR has the potential to benefit learning further through enabling the user to feel as if they are in the virtual world – a concept known as presence – and through empowering the user to use body motions that match their actions in the virtual world, or congruent gesture [1]. Presence is thought to contribute to a learner's attention and engagement [1], and has been identified to be influenced by a number of factors, one of which is immersion [5]. Though the aforementioned studies of Second Life cite immersion as an advantage, immersion has been found to be lower in laptop experiences in contrast to HTC Vive ones [5]. Additionally, SL's use of mouse and keyboard to perform laboratory actions, e.g. dispensing fluid from a burette in the study of college students [2], lacks congruence. Consequently, learners may not be achieving the stronger learning signals and memory traces believed to be associated with congruent gesture [1].

III. Design and Implementation

Our goal is to create an immersive titration learning experience, and provide compelling virtual fluid interactions with physical tactile interactions. The titration experience is made up of virtual glassware with fluid simulation and a virtual-physical haptic burette. The lab experience will also include a student's laboratory manual and pre- and post-assessments.

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A. Virtual Lab Development

To provide a rich VR learning experience, we build our virtual lab with a state-of-the-art game engine, Unity 2019.3. To provide high fidelity, visually compelling fluid interactions, we take advantage of the Obi Fluid asset from the Unity Asset Store. All virtual chemistry equipment pieces were created in the computer-aided design software Fusion 360. Our preliminary Unity scene consists of a cylindrical beaker inside and a burette suspended above it.

At the start of the experience, the software spawns clear fluid in the beaker. Meanwhile, an Obi Fluid liquid source lies at the burette tip, able to spawn clear fluid at varying drop-wise rates or as a steady stream. Our software provides an ellipsoidal depression at the burette top mimicking a meniscus. The liquid inside the burette flows out of the burette and into the beaker at a variable rate that the user determines through the haptic apparatus, described below.

In real acid-base titration experiments, as liquid from the burette collides with the beaker fluid, a localized, reversible color change occurs between the two fluids. To simulate this, our software has the color change occur when particles from each source collide, akin to that produced by indicators in a true titration. The mixed fluids change from clear to pink, remain at pink momentarily, and then return to clear. Though any color could be chosen, pink was selected in order to imitate the phenolphthalein indicator commonly utilized in acid-base titrations. The time duration of the color cycle is programmable based on the number of particles that leave the burette. By increasing the length of time the mixed fluid remains pink, we are able to recreate the fundamental behavior students are advised to observe during a titration: that the color change will persist longer as more fluid is dispensed.

B. Haptic Burette

To further the physical embodiment of the virtual experience, students can also use a 3D printed haptic burette, which uses electronics to map physical interactions with the burette stopcock dial to the virtual world. The haptic burette consists of three parts. The first part of this system is a 3D printed burette, which was developed in a computer-aided design software, and will be provided as an open design for students to print. This 3D printed burette is propped using a commonplace burette stand. The second component is a potentiometer with a 3D printed dial attached to measure the turning of the stopcock dial. Finally, an Arduino Uno manages the communication with the virtual reality software.

As the user turns the dial on the physical burette, the dial on the virtual burette also turns. The physical dial changes the resistance on the potentiometer. The values are read by the Arduino, and then the Arduino sends the values over to the Unity game scene. The virtual dial movement is mapped to the change in potentiometer resistance. Fig. 1 and Fig. 2 showcase the relationship between the physical and virtual burettes.

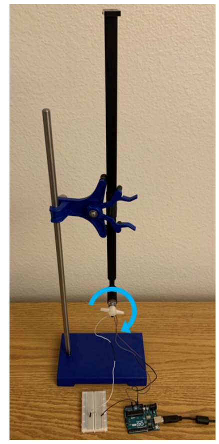

Fig. 1. Physical Burette.

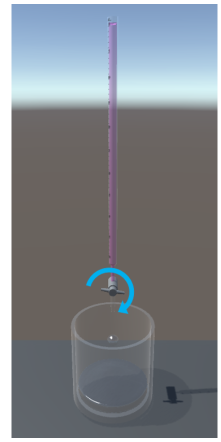

Fig. 2. Virtual Burette.

C. Titration Experience

In performing this experiment, the student's objective is to determine concentration of an acidic solution, e.g. a water sample collected from a pond. The Obi Fluid in the beaker represents this unknown solution, called the titrand. The burette fluid represents the titrant, or a basic solution whose concentration is known. As such, this experience assumes that the titrant has already been standardized.

The user first puts on the virtual reality headset. In our implementation, we use an HTC Vive headset. In order to track the physical burette, an HTC Vive tracker is attached to the top of the haptic burette. Once in the scene, the user is able to turn the physical dial to trigger the virtual burette to release its fluid. The amount of liquid that comes out of the virtual burette is controlled based on the angle of the dial. If the dial is horizontal, no fluid comes out of the virtual burette. If the dial is in a vertical position, the result is a full stream. Between the vertical and horizontal position, the fluid is dispensed at varying drop-wise speeds.

The users turn the physical dial until they witness a color change of the fluid in the virtual beaker. While the fluid is coming out of the burette, the meniscus of the virtual burette lowers. As the user dispenses more titrant, the reversible color change persists longer, and the user slows the rate of dispensation in order to reach accurately the point beyond which any further addition of fluid will cause a permanent color change, i.e. the endpoint. Fig. 3, Fig. 4, and Fig. 5 show the virtual fluid interactions. Though the color change is intended to be pink, these images display reddish color. Color gradients are still being explored.

After the endpoint is achieved, the user halts dispensation and reads the meniscus of the titrant to determine the volume of titrant dispensed. With this measurement, the user will need only to be informed of the initial volume of the acid and the concentration of the basic standard in order to determine the concentration of the acid, provided in the laboratory manual.

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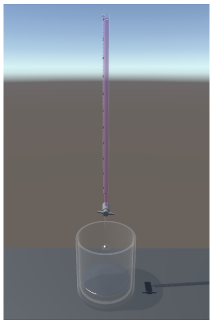

Fig. 3. Initial Droplets leaving burette.

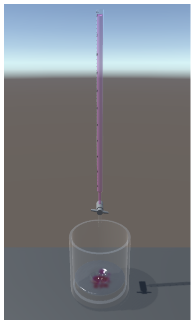

Fig. 4. Burette and beaker fluid mix.

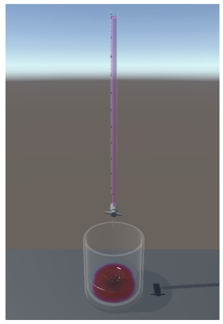

Fig. 5. Indicator shows the color change.

IV. Future Work

After finalizing the fundamental chemical behaviors of the experience, the aim is to surround the experience in curriculum for potential use in an online course. We first plan to develop a laboratory manual that contains pre- and post-experiment learning material. This has been identified as an effective strategy for overcoming common obstacles in virtual experiments [6]. We are also interested in incorporating on-screen elements to guide the user through procedural steps, for these have demonstrated effective in improving virtual learning [7]. We then intend to perform user studies that assess the learning outcomes associated with an acid-base titration, devoting particular attention to conceptual learning outcomes, which have often been ignored in studies of such immersive virtual learning environments as VR [8].

A longer-term goal is to fully develop a multitude of chemistry experiments in virtual reality with corresponding physical haptic devices. For example, we envision chemistry experiments with temperature change or viscosity change. Additionally, each of these experiments will come with lab manuals and procedures which the user can interact with and follow in the virtual world. We plan to make these experiments accessible to professional developers, as well as to high-school and college students for curriculum development and deployment.

V. Conclusion

In this works-in-progress paper, we have developed a virtual reality acid-base titration experience with a corresponding physical haptic burette. This experience incorporates rich fluid interactions with chemical color changes and enables the user to interact with the virtual scene through a physical burette. We believe that virtual reality can has the potential to transform remote learning. We plan to further develop chemistry curriculum which can actively engage students and improve learning outcomes.

References

[1] M. C. Johnson-Glenberg, "Immersive vr and education: Embodied design principles that include gesture and hand controls," *Frontiers in Robotics and AI*, vol. 5, 2018. [Online]. Available: https://doaj.org/article/b668b164dbf74d59acde3253270e2aaf

[2] K. Winkelmann, W. Keeney-Kennicutt, D. Fowler, and M. Macik, "Development, implementation, and assessment of general chemistry lab experiments performed in the virtual world of second life," *Journal of Chemical Education*, vol. 94, no. 7, p. 849, 2017.

[3] K. Winkelmann, M. Scott, and D. Wong, "A study of high school students' performance of a chemistry experiment within the virtual world of second life," *Journal of chemical education*, vol. 91, no. 9, pp. 1432–1438, 2014. [Online]. Available: http://dialnet.unirioja.es/servlet/oaiart?codigo=4855856

[4] N. Ali, S. Ullah, A. Alam, and J. Rafique, "3d interactive virtual chemistry laboratory for simulation of high school experiments," 10 2014.

[5] A. Dengel and J. Maegdefrau, *Presence Is the Key to Understanding Immersive Learning*, 06 2019, pp. 185–198.

[6] B. Stahre Wästberg, T. Eriksson, g. karlsson, m. sunnerstam, M. Axelsson, and M. Billger, "Design considerations for virtual laboratories: A comparative study of two virtual laboratories for learning about gas solubility and colour appearance," *Education and Information Technologies*, 01 2019.

[7] S. Ullah, N. Ali, and S. U. Rahman, "The effect of procedural guidance on students' skill enhancement in a virtual chemistry laboratory," *Journal of Chemical Education*, vol. 93, no. 12, pp. 2018–2025, 2016. [Online]. Available: http://search.proquest.com/docview/1969014559/

[8] A. C. Muller Queiroz, A. Nascimento, R. Tori, and M. da Silva Leme, *Immersive Virtual Environments and Learning Assessments*, 06 2019, pp. 172–181.

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