Research Paper

Using Virtual Reality (VR) as a Supplement to Lab Activities in Chemistry Classes: Effects on Student Self-Evaluation of Lab Skills

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Abstract

Virtual reality can offer an engaging and kinesthetic simulated laboratory experience. The player progresses through various laboratory tasks and is given a score based on their accuracy, precision, and efficiency in completing each task. The program can address many issues that are taught in introductory chemistry labs, but does so in a way that would be difficult to replicate in a face-to-face laboratory setting. The virtual environment can provide unlimited samples for students to use (the lab can be refreshed with the pull of a virtual lever), does not require professional supervision for safety, evaluates students on results (we can do this to an extent when an experiment is completed, but without the ability to trace mistakes back to each individual moment of an experiment), and is legitimately enjoyable (based on several semesters of student feedback). Students not only enjoy doing the assignment, but report increased confidence in performing lab activities.

Keywords: Virtual Reality, teaching/learning strategies, simulations, student experience, science education, community college

Using Virtual Reality (VR) as a Supplement to Lab Activities in Chemistry Classes: Effects on Student Self-Evaluation of Lab Skills

My interest in using virtual reality (VR) as an educational tool began during my first ride on a virtual roller coaster through a dinosaur park (in the friendly confines of the campus library). I immediately recognized a way to connect with students that would bring course material to them in a different way, but could fully capture their attention.

The gap between chemistry content and the potential of VR was bridged when a copy of HoloLab Champions (from Schell Games) was obtained. The HoloLab Champions (played through Steam on a Meta Oculus gaming system) program places the player in a virtual laboratory presented in a game show format and introduces many of the issues that we are teaching students in the introductory chemistry labs in a way that would be difficult to replicate in an actual laboratory. The virtual environment can provide unlimited samples for students to use as the lab can be refreshed with the pull of a virtual lever, allowing students to practice technical skills repeatedly if necessary without any loss of laboratory chemical supplies. Virtual experiments do not require professional supervision for safety and students complete the experiments individually, eliminating students copying classmates' techniques instead of coming up with their own procedure. The program can evaluate students on experimental results in a manner that is not practical for a face-to-face lab where the instructor cannot trace individual mistakes back to each moment of an experiment (for example, an instructor in a lab with up to 20 students cannot observe every individual measurement a student makes for accuracy, usually only finding out something went awry in an experiment when looking at the final calculation).

A level of assessment is built in to HoloLab Champions, since it is a game, it constantly keeps score as the player/student progresses through

each set of experiments – completion of an experiment would indicate that learning objectives have been met, a numerical score could be used as a means of establishing a grading scale for the experiment. This study evaluates how student self-evaluation of their laboratory skills was improved through playing HoloLab Champions. A guide for instructors to use HoloLab Champions VR game as a supplement to laboratory instruction has been published through the North Carolina Virtual Learning Community (Carpenetti, 2022).

Background and Literature Review

Laboratory exercises have long been considered an integral part of chemistry and physical science classes (Hofstein, 2004); research has shown that active learning methods, such as laboratory exercises, are significantly more effective at increasing student performances than traditional lecture-style teaching methods (Freeman et al. 2014). The use of computer content to supplement teaching in a physical laboratory has been a reality for over two decades, but has become more relevant recently as a result of shifting away from face-to-face instruction in response to the COVID-19 pandemic (Reeves et al., 2021). In many cases, laboratory-based disciplines have been forced to find more adaptive methods to provide access to equipment and experiments that are crucial to students acquiring content knowledge related to laboratory techniques (Vasiliadou, 2020). Virtual laboratory experiments feature some form of immersive technology that simulates a physical laboratory. Ideally the interactions would closely simulate the manipulation of equipment involved in an in-lab procedure. (Stanney & Cohn, 2012, Georgiou, J et al., 2007). Studies into the use of VR have focused mainly on knowledge acquisition in comparison to physical laboratories (Reeves & Crippen, 2021, Hu-Au & Okita 2021, Heradio, et al., 2016) and not on the development of lab skills. Studies of learning outcome achievement have shown that students participating in virtual labs generally have a higher rate of outcome achievement than students engaged in a traditional lab, though available studies primarily focus on content knowledge and not practical lab skills (Brinson, 2015). A study of VR Labs with respect to knowledge, self-efficacy, and enjoyment has been published (Meyer et al., 2019) but did not document student's perceptions of the experience. This study focuses on student's perceptions of their laboratory skills and how participation in virtual reality exercises affects those perceptions.

While there is a good amount published work relating to using virtual reality in physical science courses, there is not much research focusing specifically on community colleges. A study evaluating the use of virtual reality for presenting case studies related to workplace safety in online asynchronous classes in a community college setting showed an increase in student engagement compared to text-based case studies (Madathil et al. 2016) and an evaluation of using augmented reality for teaching skull anatomy in a community college setting found that participants who experienced the augmented reality skull application demonstrated an increase in knowledge as assessed by a post-knowledge quiz, compared to their baseline knowledge

determined by a pre-knowledge quiz; but the effect size was equivalent to participants who studied with a textbook and plastic skull model. (Duncan -Vaidya and Stevenson 2020).

Methods

HoloLab Champions, a virtual reality chemistry lab simulation game played on the Meta/Oculus VR system, has been used for several semesters as a supplement to laboratory exercises in general chemistry courses (CHM 151 and CHM 152, General Chemistry I and II, in the North Carolina Community College System Catalog). Student response to the assignments was very positive, prompting a study to determine whether, in addition to having fun playing the game, students were improving in laboratory skill. Craven Community College is only set up for one student to participate in the game at a time (the game requires a Steam account, a dedicated PC, and an Oculus headset all of which is located in the campus library, not in the chemistry lab) – this limitation makes it difficult to evaluate students formally, as students will, by necessity, be participating in the game at different stages of the lab progression of the course they are enrolled in. To evaluate student's experience with participating in the VR game a survey addressing confidence in various lab-related activities was developed that students could complete prior to and immediately after playing HoloLab Champions.

The survey consisted of seven questions, four relating to lab techniques, two to lab circumstances, and one relating to the assignment to play the VR game (Table 1).

Table 1
Survey Questions

VR Survey Questions
I am comfortable doing mass measurements in the lab.
I am comfortable doing volume measurements in the lab.
I am comfortable performing lab activities with minimal supervision (figuring things out on my own).
I am comfortable identifying how to accomplish an experimental goal without a specific procedure to follow.
I am comfortable using a volumetric pipette.
I am comfortable lighting and using a Bunsen burner.
Playing HoloLab Champions was a positive experience.

Note. Answer choices provided to the students were: Strongly agree (1), Moderately agree (2), Slightly agree (3), Neutral (4), Slightly disagree (5), Moderately disagree (6), and Strongly disagree (7). A version of the survey was completed before students reserved a time slot to play HoloLab Champions and after the playing experience.

The survey was administered to 67 students enrolled in either General Chemistry I or General Chemistry II in the Fall 2021 and Spring 2022 semesters.

Results

Numeric results of the survey are presented in Table 2 and will be described in more detail by question.

Measuring Mass

Mass measurements are one of the more straight-forward activities performed in a chemistry lab, generally involving setting an object on the pan of an analytical balance and reading the display. Some complexity can arise from needing to subtract the mass of a container to arrive at the mass of a sample within that container or ensuring that the balance is 'zeroed' before the measurement is performed, but in general students were very confident in their abilities with regards to measuring mass with a pre-activity score of 1.39. Even with this already very low score, student's self-evaluation after participating in the VR experiment dropped to an average of 1.18, a change of -0.21 indicating an increase in confidence with measuring masses.

Table 2
Survey Results

Question	Pre-activity	Post-activity	Change
Mass	1.39	1.18	- 0.21
Volume	1.82	1.29	- 0.53
Working on own	2.46	1.68	0.78
Working without procedure	3.50	2.29	- 1.21
Pipette	2.04	1.46	- 0.58
Burner	1.39	1.21	0.18
HoloLab Champions?	4.00	1.39	- 2.61

Measuring Volume

General volume measurements can be a bit more complicated compared to mass, involving reading the meniscus of a liquid sample interacting with the walls of the container and needing to evaluate position relative to lines on the measuring device instead of a digital readout. Student's initial confidence was still fairly high, a pre-activity score of 1.82, though lower than for mass measurements. After the VR activity student scores fell to 1.29, a change of -0.53, showing a larger increase in confidence relative to that recorded for mass measurements.

Working in the Lab with Minimal Supervision

Working alone in a chemistry lab is not regarded as a safe practice, but from a teaching perspective it would be useful to isolate a student from peers so that the work they do on an experiment is truly their own. Students initially evaluated themselves as less confident in working on their own than in performing mass or volume measurements, with a pre-activity score of 2.46. After playing HoloLab Champions, where the student is the only one in the virtual laboratory, their confidence improved by -0.78 to a post-activity average of 1.68, slightly better than moderately agreeing with being comfortable figuring things out on their own.

Working in the Lab without a Procedure

An important skill for a developing scientist is an ability to design experiments to evaluate different hypotheses, often introductory classes provide students with exact instructions to follow and do not allow students to develop this set of skills. This question had the highest (least confidence) score of the questions related to working in the physical laboratory, 3.50 pre-activity. This section also showed the biggest change among the questions related to physical laboratory skills, with the post-activity score falling to 2.29, a change of -1.21, indicating a large increase in confidence working without a specific procedure.

Using a Volumetric Pipette

A volumetric pipette is an instrument used to very precisely measure small amounts of liquid. It involves fine motor skills and dexterity in a way that many other introductory techniques do not and is often frustrating for students as a result. Students initially reported less confidence with the pipette than with other volume measurement techniques, pre-activity for pipette was 2.04 (1.82 for other volume measurements). A similar change in confidence was observed after participation in HoloLab Champions with the score for using a pipette dropping by 0.58 to 1.46 (similar to the drop seen for other volume techniques).

Using a Bunsen Burner

Lighting a burner is not a complicated activity and many students will already have similar experiences lighting gas grills, blow torches, fireworks, etc. but the springing to life of the flame can be disconcerting to some. Students began very confident in lighting a burner, pre-activity at 1.39, but some of the students who were less than completely confident did lower their scores after participating in HoloLab Champions as the post-activity score dropped to 1.21, a change of -0.18.

Playing HoloLab Champions was a positive experience.

None of the students involved in this study had played HoloLab Champions prior to participation, so the beginning score for this question was completely neutral, pre-activity 4.00. This was the highest pre-activity score, so it did have more potential to change in the positive direction, but the results were overwhelmingly positive, with the post activity score dropping by 2.61 points to a final post activity score of 1.39.

Discussion

Students clearly enjoyed the assignment to play HoloLab Champions, which is not something that can be said about many assignments. In addition to enjoying the assignment, student's self-evaluations showed an across the board improvement for all categories measured. The results clearly show that virtual reality can be an effective supplement to laboratory instruction, improving student's confidence in their ability to perform measurements, their ability to work in the laboratory without help, and to figure out how to design experiments on their own.

One caveat that should be considered is the access students have to the VR system. This is an activity, at present, that requires students to reserve time in the library to play HoloLab Champions and the available equipment affords only one player at a time (a reasonable time for a novice player to complete an experiment in the game is 45-60 minutes), as such this is an activity that must occur outside of normal class or laboratory hours and any assignment should

account for a enough time for all class members to be able to find time outside of their schedule to participate. There may be some benefit to students going to play in pairs, as the computer screen can allow a spectator to see what the player is seeing inside the VR headset and help with the experiment, but this minimizes students developing the ability to work and solve problems on their own.

Conclusion

HoloLab Champions has lived up to my expectations for the potential of virtual reality to be effective as a teaching tool for chemistry. To date, students have been universally positive about the experience from both educational and entertainment perspectives. Many students have sought to incorporate VR while engaging in other areas of their college life post introduction to the HoloLab Champions game. Increases in the use of VR technology should lead to the development of new and better educational applications to supplement your teaching and your students' learning.

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Author's Note

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