Exploring Differences in Student Learning and Behavior Between Real-Life and Virtual Reality Chemistry Laboratory Experiments

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Abstract: A 2x1 between-subjects study compares whether Virtual Reality (VR) chemistry experiments can produce similar learning results compared to Real-Life (RL) chemistry experiments. Results indicate content knowledge, experiment comprehension, and laboratory safety knowledge were comparable, but behavior in the laboratory was significantly different. Though not significant, how students elaborate and reflect in the two environments differed, possibly due to different levels of anxiety when handling physical or virtual chemicals.

Introduction

Due to the lack of financial resources in maintaining safe and well-stocked laboratories, many chemistry classes are becoming more lecture-based and forced to forego laboratory experiences (Bretz, 2019). VR technology can potentially provide inexpensive, rigorous content and immersive experiences to support hands-on science learning (Castelvecchi, 2016). The important question is whether VR environments can be used as a potential alternative to the costly traditional real-world science laboratory.

Our first hypothesis is that there will be no significant difference between the two environments in learning and behavior, since RL hands-on chemistry experimentation is possible through VR simulations with hand-held controllers that can manipulate VR objects. Winkelmann, Scott, and Wong (2014) found students produced similar lab reports for virtual experiments in Second Life compared to RL experiments. The second hypothesis is that participants in the VR condition may not exhibit the same level of care and attention during the experiment due to the lack of physical contact with chemicals, or exhibit atypical behaviors due to the immersive game-like VR environment.

Methodology

Forty education major graduate students from a private university in New York City ages 20 to 42 years old participated in the study. Thirty-seven female and three male students participated. A 2x1, between-subjects design study compared whether learning in Virtual Reality (VR) chemistry experiments (experimental) can produce similar learning results compared to Real-Life (RL) chemistry experiments (control). Participants were randomly assigned to the RL traditional science lab experiment or VR science experiment in VR (see Figure 1). Participants saw a 9-minute video lecture on general chemistry content prior to the lab session (e.g., chemical vs. physical change), and lab safety information (e.g., wear goggles), followed by a pretest. Participants were given a 5-minute training session to familiarize themselves with the environment, VR (see Figure 2) or RL (see Figure 3), before engaging in two chemistry experiments. A short experiment comprehension assessment followed each chemistry experiment. A final posttest was administered at the end of the study. Participants were also video recorded to analyze lab behaviors.

Materials and measures

The chemistry content used the NGSS 2013 Middle School Physical Science Standard on chemical or physical reactions. The first *Single Mixture* experiment involved mixing anhydrous copper (II) chloride with water then introducing aluminum metal to the aqueous solution. The second *Multiple Mixture* experiment involved mixing hydrochloric acid, lead nitrate, copper sulfate, and mossy zinc. The pre-posttest measures include content knowledge (e.g., *Define chemical change*.), experiment comprehension (e.g., *Is heat generated when mixing lead nitrate & copper sulfate?*), and laboratory safety knowledge (e.g., *Can you return unused copper sulfate into the original container?*). Each measure consisted of Basic (e.g., *define physical change)*, Inference (e.g., *Does creating cement involve physical or chemical changes?)*, and Application questions (e.g., *boiling an egg. Is this a physical or chemical change?).* Videos were coded for Laboratory safety behaviors on Procedures and Skills (i.e., wearing gloves, eye goggles, handling thermometers and scales), and Clean-up behaviors (i.e., dispose of solids in trash, liquids in the sink).

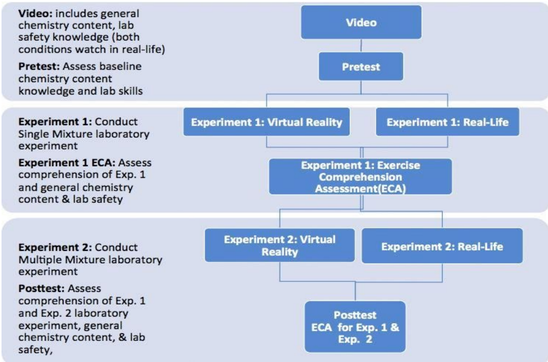

Figure 1. Study Procedure

Figure 2. Real-life laboratory

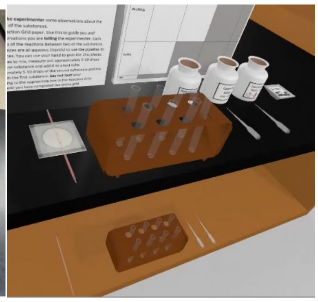

Figure 3. VR

laboratory

Results and discussion

For general chemistry content, there were no significant differences between the VR and RL conditions (t(38)= 0.518 , p = 0.607). The question type analysis revealed significant pre-posttest increases for Inference (t(19)=2.459, p<0.05) and Application questions (t(19)=3.107, p<0.05) but not Basic questions. For experiment comprehension, there were no significant differences between the two conditions for both the Single Mixture (t(38)= 1.175, p = 0.247) and Multiple Mixture experiment (t(38)= 1.52, p = 0.137). For the Single Mixture assessment both conditions showed similar decrease for basic questions, but only the RL condition had a significant decrease in performance for inference questions (t(19)=2.698, p<0.05). Possibly the absence of anxiety in handling real chemicals allows the learner to elaborate and reflect more on the content in VR compared to RL.

For lab safety knowledge the VR condition scored significantly higher than RL on the pretest (t(37)=5.669, p< 0.01). Possibly, differences in lab environment may have had an effect. The RL participants answered the pretest surrounded by laboratory equipment, while VR participants were in a computer room taking the pretest before entering the VR environment. This may have led to less anxiety for VR participants making it easier to concentrate. VR condition had marginal gains from pre to posttest in laboratory safety knowledge, while the RL condition had a significant increase (t(19)= 2.761, p<0.05). Possibly the lack of physical contact may have desensitized VR participants to their anxieties over time (Triscari, Faraci, Catalisano, D'Angelo, & Urso, 2015). For lab safety behaviors, the RL condition showed significantly higher lab safety behaviors than the VR condition (t(37)=5.669, p< 0.01). Both conditions showed decrease in behavior from first to the second experiment. There was a larger decrease in clean-up behavior in the VR than in the RL condition. Possibly due to less consequences in VR with poor cleanup or the difficulty to manipulate items in VR compared to the RL labs.

Important implications include foundational knowledge of how learning occurs in both VR and RL environments, and identifying the type of knowledge (e.g., basic, inferential, applied) and behavior seen in each environment. Such findings can inform pedagogical risks and specific approaches to new learning environments.

References

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