Teaching Science Lab Safety: Are Virtual Simulations Effective?

By

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ABSTRACT

The purpose of this study was to investigate the impact of immersion on knowledge, cognitive load, and presence in a simulation designed to deliver a lesson on science lab safety training. 108 participants were randomly assigned to one of three conditions: high immersion (played an interactive simulation about lab safety in a VR headset), medium immersion (played the same interactive simulation on the computer), or low immersion (watched a video and read about lab safety procedures). Participants completed a pretest, a science lab safety training, a posttest (same as the pretest), a questionnaire with subjective presence questions, and a questionnaire with subjective cognitive load questions. Participants were again asked to complete a follow-up test (same as the pretest and posttest) a week later.

The results revealed three significant findings:

(a) Participants in the high and medium immersion conditions had significantly higher knowledge scores at posttest and follow-up than their peers in the low immersion condition,

(b) Participants in the high and medium immersion conditions reported higher presence scores than participants in the low immersion conditions.

(c) Correlation coefficients suggested that the higher the immersion and presence, the higher the knowledge scores are at posttest and follow-up.

In addition, multiple hierarchical linear regression models were conducted out of which one was significant.

ACKNOWLEDGMENTS

I am eternally grateful to each of the members of my dissertation committee: Dr. Mina Johnson-Glenberg, Dr. Brian Nelson and Dr. Robert Atkinson. I couldn’t have done this without their patience, support and guidance. I wish to thank my parents who have taught me that hard work and perseverance is more important than talent. Lastly, I am grateful to my wife Meredith, and my daughter Eleni, for their endless support during this adventure. They are my “why”.

DEDICATION

To our parents for their guidance, to our teachers for their inspiration, to our spouses for their love, to our kids for the future.

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Chapter 1

INTRODUCTION

The goal of this dissertation study was to investigate the impact of learner immersion on knowledge, cognitive load, and presence in a simulation designed to deliver a lesson on science lab safety training. Specifically, the study addressed the following research questions:

(a) Do knowledge scores as measured by a pretest, a posttest and a follow-up differ as a function of the different modes of immersion?

(b) Is there a relationship between time of test and the level of immersion?

(c) Does cognitive load as measured by the NASA Task Load Index differ as a function of the different modes of immersion?

(d) Does presence as measured by a subjective presence questionnaire differ as a function of the different modes of immersion?

(e) Are there significant correlations between variables?

(f) Can knowledge scores be predicted from the independent variables?

Two independent variables were manipulated in this study: immersion (high, medium, low) and time of test (pretest, posttest, follow-up). The dependent variables were knowledge, presence, and cognitive load scores. Participants in the high immersion condition played an interactive simulation about lab safety in virtual reality headsets, participants in the medium immersion condition played the same interactive simulation about lab safety on a computer, and participants in the low immersion condition watched a video and read a set of rules about science lab safety.

Virtual Reality (VR) has become a mainstream consumer platform. Oculus, Vive and Google Daydream have produced VR experiences that are compelling enough for consumers to consider the relatively expensive barrier to entry and adopt these technologies. VR transports people to a different world, a substitute reality where they can interact with objects, people, and environments, the appearance of which was bound only by the limits of human imagination (Lanier, 1992; Rheingold, 1991; Sutherland, 1968). In the early years of VR, futurists heralded it as a transition in the ways humans would experience media, communicate with one another, and even perform mundane tasks (Tyagi, 2011). Throughout the years, VR continued to captured our imaginations for its ability to substitute our physical environment and our sensory experiences. However, it did not meet expectations primarily because of computing limits.

Early examples of attempts to simulate environments were devices like Edward Link's flight simulator (an electromechanical device that was controlled by motors linked to the rudder and steering column), and Morton Heilig's Sensorama (an arcade-style theatre cabinet that would stimulate all the senses). Since then, advances in computing have enabled high fidelity virtual reality experiences to be delivered on platforms like Oculus and Vive and in mobile phones (Google Pixel on Daydream, Samsung GR VR). Consumers have been slowly but steadily embracing the technology, and the time is right for VR in education in part because of the reduction of cost of hardware, but also because of the benefits to learning that researcher believe VR holds

Freina and Ott (2015) conducted a literature review about the use of VR in education and identified the advantages for education:

1. VR allows a direct experience of objects, events, and spaces that are physically out of reach.
2. VR supports training in safe environments.

They also identified that the primary motivation of using VR is the opportunity to experience situations that cannot be accessed. For example, VR can enable learners to travel in time and experiment with different historical periods. VR can enable learners to explore spaces that are physically inaccessible or dangerous, like the solar system or war zones. VR can enable learners to learn in situations that are physically and psychologically taxing, such as firefighter training and neurosurgery.

A key aspect of modern VR experiences that may bolster learning is their high level of immersion. Realistically rendered VR experiences may help learners experience high levels of immersion, which can in turn bolster their learning and engagement (Winn and Windschitl, 2000; Merchant, Goetz, Cifuentes, Keeny-Kennicut, & Davis, 2014). The purpose of this dissertation study was to investigate the impact of a lab safety training curriculum delivered through three levels of immersion: high (virtual reality), medium (desktop computer), low (video and text) on participant learning, presence, and cognitive load.

The following sections explore simulations and virtual reality, their general applications in education, and their specific application to science education. The concepts of immersion and presence and their usefulness in virtual simulations are discussed. The theoretical frameworks of embodied cognition, constructivism, problem-based learning and how they inform educational VR are examined. Finally, the concept of cognitive load and its potential impact in VR experiences are briefly outlined.

Simulations

Simulations are interactive learning environments in which learners can experience real-life situations. In simulations, learners can safely test their hypotheses of the effects of variables on the intended outcomes (Tobias & Fletcher, 2010). Learners in simulations can also practice scenarios using virtual versions of devices and tools that otherwise would be cost-prohibitive. For example, anatomy lessons that include frog dissection are very common and used to teach anatomy. Vfrog is a popular simulation that allows students to conduct frog dissection numerous times using virtual apparatus (Lalley et al, 2010). Anatomy procedures such as dissections that take place in laboratories impose a financial burden to institutions, and may conflict with the learner's personal beliefs about conducting such dissections. Enabling leaners to experience these dissections in a virtual simulation provides learners with unlimited practice time in a safe environment, something not feasible in a traditional environment. Medical students, for example, could practice in a virtual simulation prior to practicing on real-life patients reducing the risk of medical malpractice and severe injuries.

Simulations are useful for both presentation and practice if used in conjunction with other methods of instruction. Students performed better when some form of guidance was provided even in practice mode compared to those where there was no guidance provided (Lee, 1999). Sitzmann (2011) and Vogel et al. (2006) conducted a meta-analysis in which they analyzed the effects of interactive computer-based games and simulations and found statistically significant positive impacts on learning outcomes. Vogel et al. (2006) also found that students performed better when they controlled their navigation in the virtual environment rather than when the teacher controlled the learning environment. In the same study, students in the virtual learning environment where outperformed by students in the traditional group when the learning activity was controlled by the computer programs. Stanney and Hash (1998) investigated the potential of minimizing cybersickness through mapping the users' level of control directly to the movements necessary to complete a task, and found that user-initiated control that users had in the virtual environment reduced the level of sickness they experienced.

Sitzmann (2011) researched the effects of games and simulations in enhancing work-related knowledge and skills. Results showed the highest gain in the measure of self-efficacy (20%) as compared to procedural knowledge (14%), declarative knowledge (11%), and retention (9%). The virtual environmental characteristics such as active presentation of materials, unlimited access level to the learning materials, and presentation of the materials in a supplemental format were more effective.

Examples of uses of Virtual Environments include the creation of learning environments for use outside the laboratory. Virtual Environments (VE) have been used in exposure therapy (VRET; Gregg & Tarrier, 2007; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008; Riva, 2005; Rothbaum) to help in the treatment suffering from psychological disorders such as anxiety and phobias. Patients were gradually introduced to the negative stimulus in a virtual setting until they are desensitized and able to cope with their fear or anxiety. Examples of uses of VE treatments include acrophobia (Coelho, Santos, Silvério, & Silva, 2006), agoraphobia (Botella et al., 2007), arachnophobia (Cote & Bouchard, 2005), aviophobia (Rothbaum, Hodges, Smith, Lee, & Price, 2000), public speaking anxiety (Harris, Kemmerling, & North, 2002), social phobia (Roy et al., 2003) and post-traumatic stress disorder (PTSD; Reger & Gahm, 2008; Rothbaum, Ruef, Litz, Han, & Hodges, 2003).

Virtual environments are also being used as a tool in cognitive behavioral therapy, to help addicts cope by using virtual cues to simulate alcohol cravings (Cho et al., 2008) and nicotine cravings in cigarette smokers (Baumann & Sayette, 2006). Applications also include the use of virtual reality therapy in physical rehabilitation (Schultheis & Rizzo, 2001; Sveistrup et al., 2003). Deutsch & Mirelman (2007) used virtual environments to help stroke victimes regain their sense of balance while walking. Bryanton et al. (2006) used virtual environments to help children with cerebral palsy develop muscular coordination.

Educational Virtual Environments

An Educational Virtual Environment (EVE) or Virtual Learning Environment (VLE) can be defined as an environment that is based on a certain pedagogical model, incorporates or implies one or more didactic objectives, provides users with experiences they would otherwise not be able to experience in the physical world and reflects specific learning outcomes (Mikropoulos & Natsis, 2011).

Virtual reality was initially described as a "collection of technological hardware" (Steuer, 1992), but the description eventually shifted away from its technological focus as sytems evolved and started providing experiences that are interactive and immerse the user's senses. The early technological approach to virtual reality also failed to provide a framework for the educational use of virtual reality.

According to Mikropoulos & Natsis (2011) learning using virtual environments was first proposed in 1990 when "Bricken specified natural semantics and cognitive presence as the main features of virtual environments and constructivism as the theoritical model supporting EVEs". Subsequent definitions such as Helsel's (1992) who described VR as "a process that enables users to become participants in abstract spaces where the physical machine and physical viewer do not exist".

Practical reasons for using VR in the classroom include learner active participation, high interactivity and the potential of highly personalized experiences (Pantelidis, 1993). Educational applications of immersive systems support first-person experiences and interactions that support the construction of knowledge through a social constructivist framework (Winn, 1993). Also, virtual environments elicit a sense of presence which could be a significant element of the learning process (Winn and Windschitl, 2000). That sense of presence occurs when learners interact directly with real or virtual worlds and report the psychological feel of "being there", and although the literature lacks conclusive evidence about its effect on learning, researchers agree that it is part of the complex process of learning, and does not act in isolation (Salzman, Dede, Loftin, & Chen, 1999).

Applications of VR in Science Education

Virtual reality systems allow users to explore immersive, three-dimensional environments from anywhere (Merchant, Goetz, Cifuentes, Keeny-Kennicut, & Davis, 2014). Lee & Wong (2014) state that "VR affords investigation of distant locations, exploration of hidden phenomena, and manipulation of otherwise immutable structures". For example, medical students can experience dissections with virtual cadavers

(Nicholson, Chalk, Funnell, & Daniel, 2006). Dyer & Thorndike (2000) state that "VR programs have the potential to induce the most dramatic shift in anatomy instruction since Vesalius introduced richly illustrated volumes of the human body based on careful, intricate cadaver dissections".

Teaching medical students with cadavers has been a centuries-old practice despite its high cost (Robison, Liu, & Apuzzo, 2011), the stress placed on medical students (Charlton & Smith, 2000) and instructional effectiveness for small or delicate organs (Hu et al., 2010). According to McLachlan et al. (2004), learning anatomy "requires students to view structures from multiple perspectives, coordinate and integrate structures into a comprehensive (and potentially hidden) whole". And since these tasks require high spatial cognitive resources (Stull, Hegarty, & Mayer, 2009), and manipulating these structures in a virtual environment may promote the development of "embodied," multimodal mental representations (Barsalou, 1999).

Embodied learning prepares students to engage in mental imagery or simulations in the absence of the physical structures, and, for medical students, the ability to imagine and mentally manipulate anatomical structures is a crucial skill (Stull et al., 2009). Already, online biology students are using virtual reality in this exact manner for their coursework ("ASU online biology course allows students to dissect animals — with no cutting involved," n.d.)

Immersion and Presence

The VR environment tracks user movements and their environment and composes and displays these movements digitally to the senses. The virtual environment replaces the cues of the real-world environment with digital ones. The psychological experience of losing oneself in the digital environment and shutting out signals from the physical world is known as immersion (Coulter, Saland, Caudell, Goldsmith, & Alverson, 2007).

Immersion plays a significant role in a VR environment since the degree of immersion and realism within the environment may affect the feelings of presence a user experiences when within the virtual environment.

The level of tracking and rendering in the VR environment affects interactivity which in turn can have an immediate impact on the experience. For example, a high degree of interactivity and one that is perceptually realistic could increase the effects of immersion on presence. Presence is the subjective experience of being in one environment when the user is physically located in another (Witmer & Singer, 1998). Besides the high degree of interactivity in a simulation, Witmer & Singer (1998) also list the necessary conditions for presence to occur: focus, involvement, and immersion.

A novel experience may cause learners to be more aroused thus requiring them to be broadly focused, a necessary condition for feelings of presence in virtual environment (Fontaine, 1992). Witmer and Singer define involvement as the "psychological state experienced as a consequence of focusing one's energy and attention to a coherent set of stimuli or meaningfully related activities and events." They support that the more a user focuses their attention on the VE environment, the more they become involved leading to higher feelings of presence. Finally, feelings of immersion depend on the user's feelings of isolation from the physical space, their perception of self-inclusion, and how natural the interactions within the environment are.

Slater and Wilbur (1997) defined presence as a sense of being in the virtual environment. Participants who are highly present "experience the virtual environment (VE) as more the engaging reality than the surrounding physical world, and consider the environment specified by the displays as places visited rather than as images seen." They also state that behaviors in the VE should be close to what may have occurred in similar circumstances in reality. The significant point that Slater and Wilbur's research that applies in the context of this proposed study is the relationship between presence and task performance. Slater and Wilbur suggest that the higher the degree of presence, the higher the chance participants will behave in the VE like their behavior in situations in everyday reality. Thus, presence is crucial when training surgeons or other hands-on subjects because they have to act the same way they do in the real world.

Embodied Cognition

The concept of embodied cognition supports that human cognition is connected with the interactions of the body and its physical environment. Hostetter & Alibali (2008) found evidence that body movement can facilitate the retrieval of mental or lexical items. Johnson-Glenberg, Megowan-Romanowicz, Birchfield, & Savio-Ramos (2016) found that learners in a high-embodiment experience demonstrated significantly higher retention on a one-week follow-up test on physics knowledge when compared to participants in a low-embodiment experience, even though both groups demonstrated significant learning gains at an immediate posttest.

Shepard and Cooper's (1982) research on mental imagery and rotation has shown that persons manipulate mental representations much like they would actual objects in physical space, with the time it takes to mentally rotate an image in a direct relationship with the degree of rotation. This research suggests that mental representations not only have perceptual qualities, but "they recruit processes from the motor system as well" (Wexler, Kosslyn, & Berthoz, 1998). Neuroimaging studies show that motor cortices are activated when performing mental transformation tasks (Cohen et al., 1996), and that transcranial magnetic stimulation targeted to interfere with neuronal processes in motor regions of cortex reduce mental rotation performance (Ganis, Keenan, Kosslyn, & Pascual-Leone, 2000).

The relationship between manual activity and mental rotation can be impacted by context, prior experience, and even voluntary perspectives or strategies applied by the individual. According to Kosslyn, Thompson and Wraga (2001) "participants who had previously rotated an object by hand, rather than passively observed the object being rotated by a motor, showed stronger activity in motor cortex when asked to imagine rotating displayed 3-D blocks in the same manner as the physical object." Individuals may take alternative perspectives during mental rotation which may have a differential impact on performance. Kontra et al (2015) explored the importance of physical experience in science learning and showed that brief, meaningful physical experience with science content enhances learning by activating sensorimotor brain systems used to execute similar actions in the past.

Embodied cognition advocates support that learning experiences where learners have the opportunity to use movement to learn about concepts may be superior to learning activities where physical movement is not congruent. A virtual reality environment has the ability to create user-environment interactions where users can manipulate and modify items and spaces with gestures in agreement to their learning outcomes (for example, how to wash when chemicals enter one’s eyes in a virtual environment, versus watching a video of how it is done).

Constructivism and Problem-based Learning

Dewey (1916) argued that knowledge was an active process of being in the environment, knowledge is based on the active experience, and that education should improve the reasoning process through problem-solving methods. He emphasized the notion that “education should be experimental, and experiential, and that knowledge is “based on active experience”. Constructivists support the notion that learners should be exposed to experiences where they work towards solving real-life problems. The combination of the opportunities to problem solve, along with free discovery is what constitutes new knowledge.

Virtual reality could support environments where learners are exposed to real-world, cased-based experiences that create meaningful and authentic knowledge. For example, in their pilot study, Seo et al. (2018) examined how a constructivist method in a virtual reality environment can support anatomy education. Participants in the study learned about the canine skeletal system through the manipulation of bones in the VR environment. Virtual reality environments such as the example above could enable students to learn in real situations in addition to improving their skills through practice.

Virtual reality environments can also enable problem-based learning, where learners are exposed to authentic and concrete problems in contrast with simply studying case studies. Nelson, Sadler, & Surtees (2005) used a virtual reality package to prepare students in a nursing program for clinical practice within primary and critical care settings. Ulrich, Farra, Smith, & Hodgson (2014) used a virtual reality simulation to prepare new nurses in disaster procedures, exposing them to exercises where nurses safely learned and practiced decontamination methods. Both examples above illustrate the application of exposing learners to authentic learning scenarios where problem-solving skills are required to reach a solution with vaguely defined outcomes.

Cognitive Load Theory

According to cognitive load theory, working memory and the capacity for information processing is limited. Actual learning can be inhibited if the summed effect of cognitive load on the task and the learning process exceeds the cognitive capacity of the learner. The simultaneous mental integration of novel and unorganized information and complex psychomotor skills can impose an extraneous cognitive load and may result in cognitive overload that is detrimental to learning.

The cognitive load process is made up from intrinsic, extraneous and germane load (Clark et al., 2006). Intrinsic load refers to the effort associated with a specific topic as well as its inherent difficulty. Design interventions do not change intrinsic load without changing the task since it depends on the number of items that working memory needs to processes simultaneously. Standard practices in addressing intrinsic cognitive load include breaking the topic into individual parts and teaching it in isolation. Van Merrienboer and Sweller (2010) provide the example of vocabulary learning and although there are thousands of words to learn most people can learn some words because they can learn them in isolation. By contrast, learning grammar exhibits a task with a high intrinsic load because learners must attend to words as well as syntax, tense and verb endings. Extraneous cognitive load refers to how the information and tasks are presented to the learner, controlled by the learning experience designer. Lack of proper guidance within an experience, lack of information needed to complete a task and similar barriers add to extraneous load. Germane cognitive load refers to the work a learner puts into and creating knowledge. Appropriate instructional activities and material design can minimize the extraneous load and maximize germane load to ensure effective learning.

Because a virtual reality environment allows for highly concrete content and without separating critical information that contributes to split attention, a major source of extraneous cognitive load, it is hypothesized that the experience will minimize extraneous cognitive load and maximize germane cognitive load thus enabling the students to perform better.

Overview of the Study

The motivation for this dissertation study is to begin understand how virtual reality simulations can be used to effectively teach science to college students, and if the simulations can serve as alternatives to teaching lab requirements in physical labs. The purpose of this study was to investigate the impact of immersion on knowledge, cognitive load, and presence in a simulation designed to deliver a lesson on science lab safety training. Specifically, the study addressed the following research questions:

(a) Do knowledge scores as measured by a pretest, a posttest and a follow-up differ as a function of the different modes of immersion?

(b) Is there a relationship between time of test and the level of immersion?

(c) Does cognitive load as measured by the NASA Task Load Index differ as a function of the different modes of immersion?

(d) Does presence as measured by a subjective presence questionnaire differ as a function of the different modes of immersion?

(e) Are there significant correlations between variables?

(f) Can knowledge scores be predicted from the independent variables?

Two independent variables were manipulated in the study: immersion (high, medium, low) and time of test (pretest, posttest, follow-up). The dependent variables were knowledge, presence and cognitive load scores.

Chapter 2

METHOD

Participants & Design

A total of 108 participants were recruited from a large southwestern university in the US to participate in this study. They were students enrolled in undergraduate or graduate programs at the university. They participated in the study to enter a drawing for one $99 Amazon gift card. Participants were all over 18 years old. Among these participants 68 (63%) were male, 39 (36.1%) were female, and 1 (.9%) did not identify with a gender. 44 (40.7%) were freshmen, 15 (13.9%) were sophomores, 7 (6.5%) were juniors, 18 (16.7%) were seniors, and 24 (22.2%) of the participants were graduate students. 84 (77.8%) of the participants had less than two years of science experience, 17 (15.7%) had between two and four years of experience, and 7 (6.5%) had more than four years of experience with science.

The study used a pretest, posttest, followup between-subjects design in which participants were randomly assigned to one of the three conditions.

(a) High immersion,
(b) Medium immersion,
(c) Low immersion.

Measures & Instruments

A survey was used to solicit basic demographic data such as year in school (e.g. freshman), gender, major. Participants were also asked to indicate the number of years of experience with science. A combination of two science classes in high school or college indicated one year of experience, and experience was classified as beginner (less than two years of experience), intermediate (more than two but less than four years) and advanced (more than four years). The demographic survey was used to control for preexisting differences between the two groups.

A pretest (test-retest reliability, *r = .72*) with ten factual multiple-choice questions was used to measure participants' prior knowledge about safety in a science lab (e.g. why don't you clean a spill with water? Why is it dangerous to wear contact lenses in the lab? See appendix B). The pretest was developed by Labster (https://labster.com) and it is used to examine student's knowledge acquisition in their Lab Safety virtual simulations. Construct validity was assessed by checking with professors who teach an undergraduate general biology course at the university, and who use the simulations to teach lab safety in their course. The professors confirmed that the items assessed in the objective test are sufficient for safety procedures in introductory lab science courses. Each question in the pretest was scored 0 points for an incorrect answer or one point for the correct answer, therefore a maximum of 10 points. The same 10-item posttest was administered to measure participants' learning gains after the intervention. The same posttest was administered after the intervention to assess retention. To account for testing threats to internal validity no feedback was provided to participants on their performance on each testing occurrence until they completed the final posttest.

Two subjective questions (How mentally demanding was the task? How insecure, discouraged, irritated, stressed and annoyed were you?) were used to measure participants perceived cognitive load. They were adapted from the NASA-TLX (Hart & Staveland, 1988), and each of the questions was administered on a 7-point Likert scale

(Appendix C). The questions measured mental demand and frustration respectively, and were the most relevant for the purposes of this study.

Participants' presence was also measured using a 7-point Likert scale ranging from "0" (not at all) to "6" (very). There were a total of 10 statements adapted from the Witmer & Singer (1994) presence questionnaire, an internally consistent measure with high reliability. They defined presence as "the subjective experience of being in one place or environment, even when one is physically situated in another". The questionnaire included questions like "how much were you able to control events?" and "how responsive was the environment to actions that you initiated?" (see Appendix D), and questions measured the degree of control and sensory factors that can influence how much presence is experienced (*Cronbach's a* = .96).

Equipment

The Lenovo Mirage Solo headset (see Figure 1) was used to deliver the intervention in the high immersion condition. The headset is a standalone Daydream VR headset and allows users to experience virtual reality without a separate PC or smartphone. The headset uses WorldSense™ technology which allows users to lean, dodge, duck, move, avoid obstacles and move naturally in a virtual environment. Participants in the medium and low immersion conditions used desktop computers to experience each intervention.

Figure 1. Lenovo Mirage Solo headset and controller utilized in the study

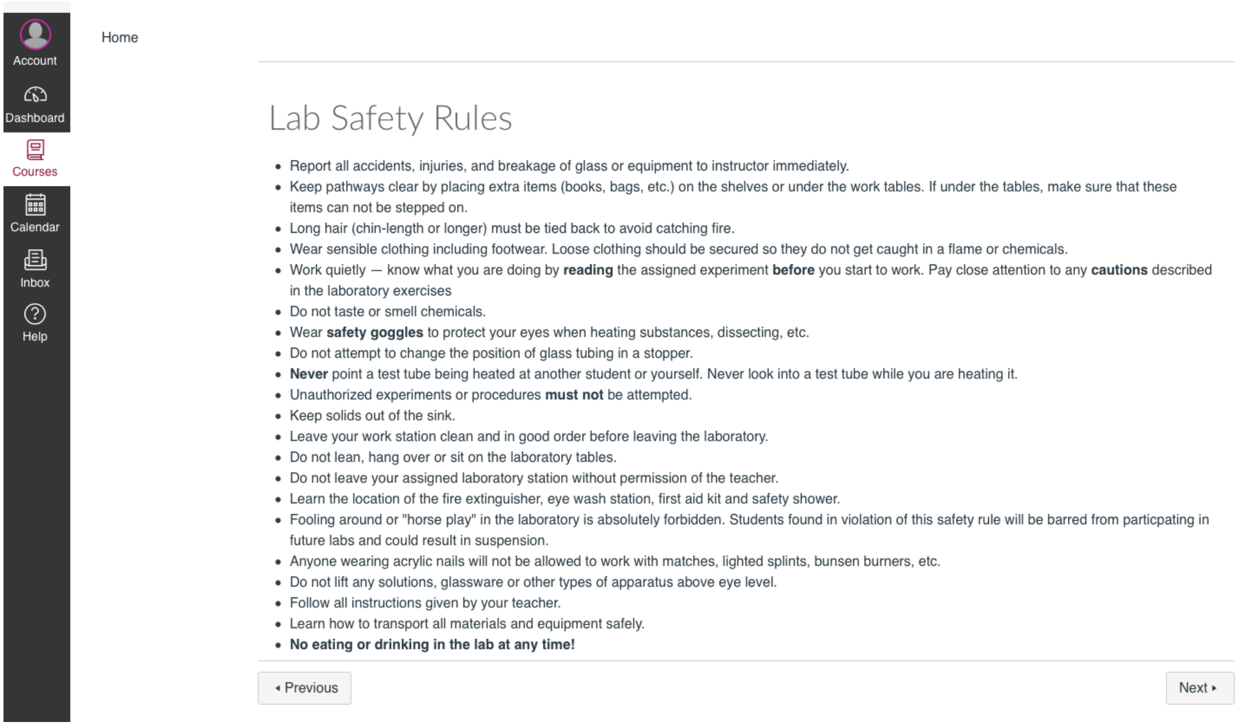
The high and medium immersion conditions used the Lab Safety Virtual Lab by Labster (see Figure 2). In this virtual simulation, students learn how to use the lab safety equipment, how to react in case of an emergency and detect and eliminate sources of danger. The lab safety simulation is the same on both mediums (VR and desktop). The low immersion condition used a lab safety video and a handout illustrating necessary lab safety procedures. The Lab Techniques & Safety video by CrashCourse (see YouTube: https://youtu.be/VRWRmIEHr3A, figure 2) covered topics like proper lab attire, how to dispose chemical safely and how to use fume hoods. Supplemental information (Figure 3) was provided to participants to expose them to additional instructional time and reinforce the content presented in the video. The supplemental information was adopted from the United Federation of Teachers (see: http://www.uft.org/chapters/lab-specialists/lab-safety-rules-for-students).


DAY 1 08:00 AM PROGRESS: 21%

Find five safety hazards and click on them.

Figure 2. The Lab Safety Virtual Lab simulations by Labster


Figure 3. Screenshot from the Lab Techniques & Safety video



Lab Safety Rules

- Report all accidents, injuries, and breakage of glass or equipment to instructor immediately.
- Keep pathways clear by placing extra items (books, bags, etc.) on the shelves or under the work tables. If under the tables, make sure that these items can not be stepped on.
- Long hair (chin-length or longer) must be tied back to avoid catching fire.
- Wear sensible clothing including footwear. Loose clothing should be secured so they do not get caught in a flame or chemicals.
- Work quietly — know what you are doing by **reading** the assigned experiment **before** you start to work. Pay close attention to any **cautions** described in the laboratory exercises
- Do not taste or smell chemicals.
- Wear **safety goggles** to protect your eyes when heating substances, dissecting, etc.
- Do not attempt to change the position of glass tubing in a stopper.
- **Never** point a test tube being heated at another student or yourself. Never look into a test tube while you are heating it.
- Unauthorized experiments or procedures **must not** be attempted.
- Keep solids out of the sink.
- Leave your work station clean and in good order before leaving the laboratory.
- Do not lean, hang over or sit on the laboratory tables.
- Do not leave your assigned laboratory station without permission of the teacher.
- Learn the location of the fire extinguisher, eye wash station, first aid kit and safety shower.
- Fooling around or "horse play" in the laboratory is absolutely forbidden. Students found in violation of this safety rule will be barred from particpating in future labs and could result in suspension.
- Anyone wearing acrylic nails will not be allowed to work with matches, lighted splints, bunsen burners, etc.
- Do not lift any solutions, glassware or other types of apparatus above eye level.
- Follow all instructions given by your teacher.
- Learn how to transport all materials and equipment safely.
- **No eating or drinking in the lab at any time!**

Figure 4. Lab Safety Rules Supplemental

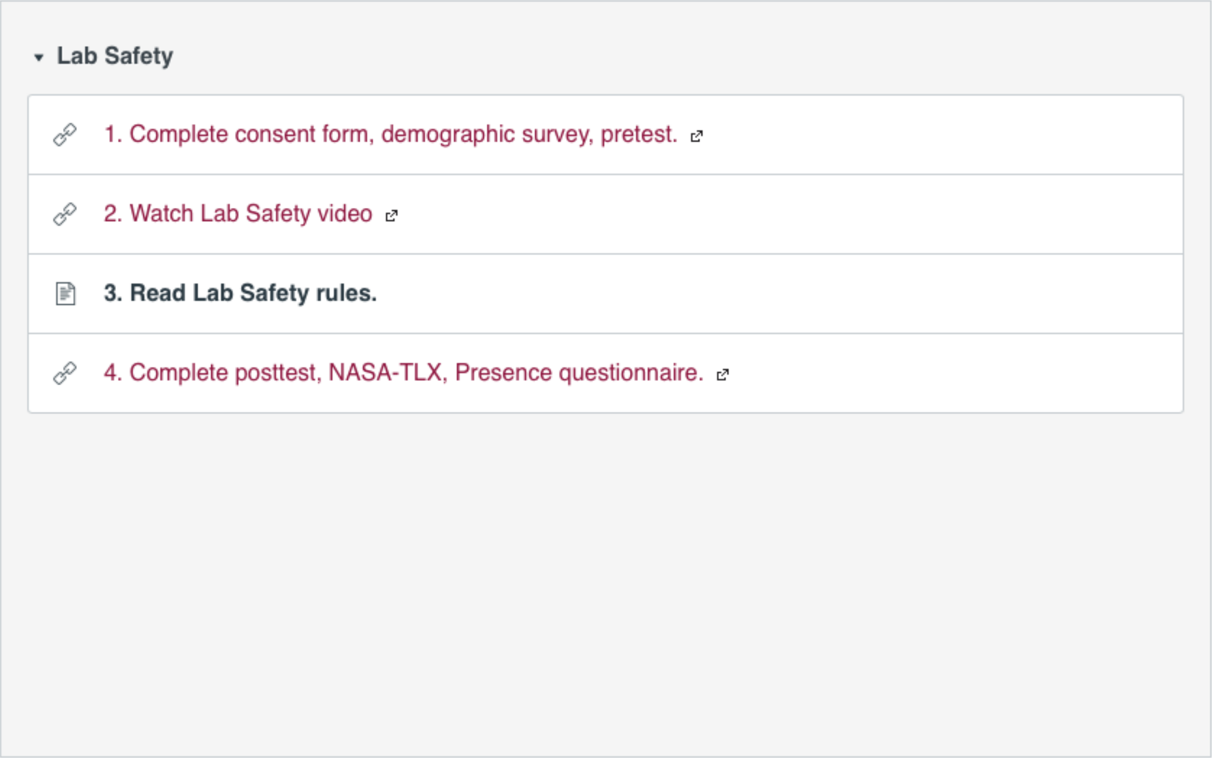
Participants in the medium and low immersion conditions accessed the intervention in a course hosted on Canvas learning management system, a software application used for the delivery of educational content. Participants in the low and medium immersion conditions were enrolled in separate Canvas courses. Participants in the high immersion conditions were not enrolled in a Canvas course, completed the tests and surveys on a laptop computer, and accessed the simulation directly in the VR headset.

Procedure

The study was conducted in a computer laboratory setting. Upon arrival, participants were randomly assigned to one of the three conditions. Participants in the low (37 participants) and medium (36 of participants) immersion conditions were enrolled in their respective course in Canvas, and were instructed to complete each section (consent form, demographic survey, pretest, simulation or video and text, posttest, NASA-TLX and presence surveys) sequentially and with no time limit. The consent form, demographic survey, pretest and posttest were delivered in a Google Form that was linked within the course.

Participants in the high immersion condition (35 participants) were not enrolled in a Canvas course, instead they were instructed to complete the consent form, demographic survey and pretest preloaded on a computer, with no time limit. They were then instructed on how to use the hand controller, put on the VR headset and start the simulation. Upon completion of the simulation, participants were asked to return to the computer to complete the posttest, and the NASA-TLX and presence surveys. Participants in the low immersion condition completed their session on 16.2 minutes average (*M* = 16.2, *SD* = 3.71). Participants in the medium immersion condition completed their session in 22.4 minutes average (*M* = 22.4, *SD* = 7.04). Participants in the high immersion condition completed their session in 25.9 minutes average (*M* = 25.9, *SD* = 6.70).

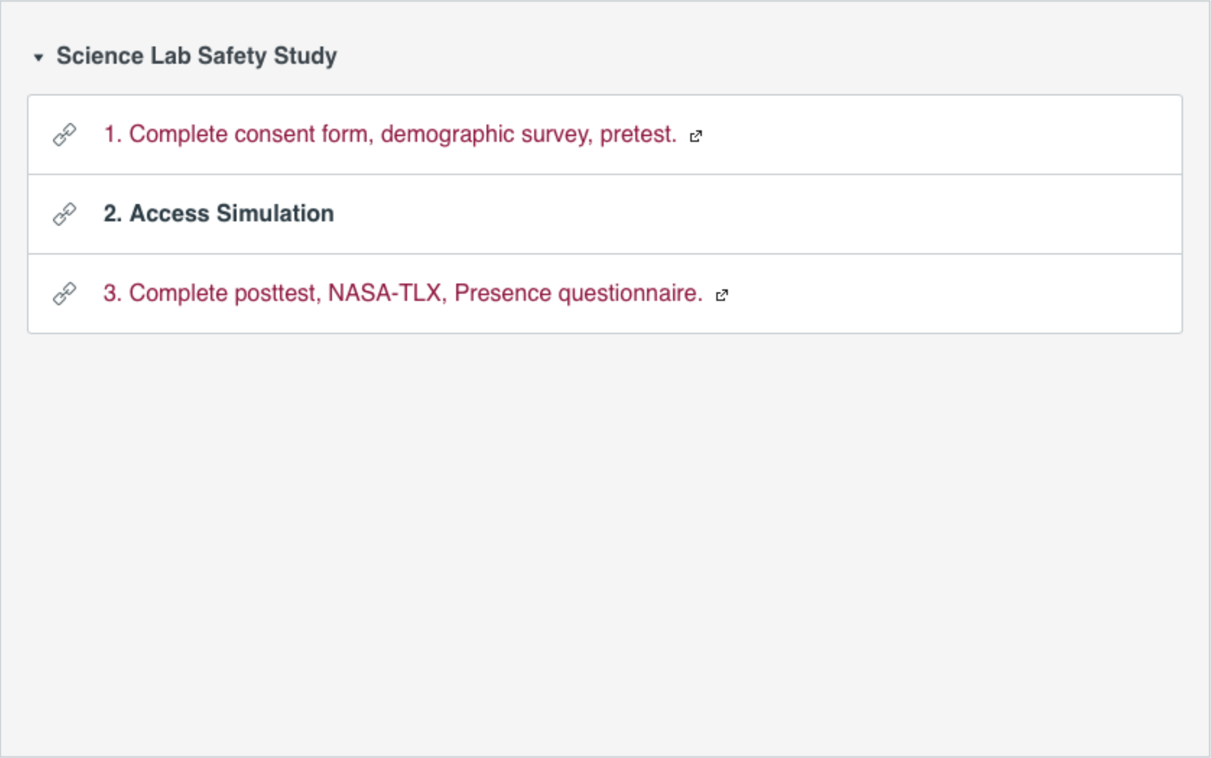
Upon completion of each session, participants were thanked and were told to look for a follow-up email in seven days for another posttest. The email contained a link to the survey and asked participants to complete it at their location. Of the 108 participants, 92 completed the follow-up questionnaire on 8 days average (*M* = 8.47 days, *SD* = 1.82 days).



Lab Safety

1. Complete consent form, demographic survey, pretest.
2. Watch Lab Safety video
3. Read Lab Safety rules.
4. Complete posttest, NASA-TLX, Presence questionnaire.

Figure 5. Sequence of activities in the low immersion condition



Science Lab Safety Study

1. Complete consent form, demographic survey, pretest.

2. Access Simulation

3. Complete posttest, NASA-TLX, Presence questionnaire.

Figure 6. Sequence of activities in the medium and high immersion conditions

Chapter 3

RESULTS

Knowledge

A two-way mixed ANOVA was used to determine whether there is an interaction between the factor of immersion and time of test on lab safety knowledge scores. There was one outlier at pretest, which had a studentized residual value of 3.17, and one outlier at posttest, which had a studentized residual value of -3.01. Both outliers were removed. There were no outliers at follow-up, as assessed by examination of studentized residuals for values greater than ±3. Both outliers were removed. Knowledge scores were normally distributed, as assessed by Normal Q-Q Plot. There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$). There was homogeneity of covariances, as assessed by Box's test of equality of covariance matrices ($p = .058$). Mauchly's test of sphericity indicated that the assumption of sphericity was violated by the two-way interaction, $x^2(2) = 15.49$, $p > .001$. There was a statistically significant interaction between immersion and time of test, $F\ (3.43, 154.14) = 42.77$, $p < .001$, partial $\eta^2 = .488$

Overall, there was not a statistically significant difference at pretest, $F\ (2,104)$, p = .408, *partial* $\eta^2 = .017$. There was a statistically significant difference at posttest, $F\ (2,104) = 88.13$, $p < .001$, $\eta^2 = .629$, and a statistically significant difference at follow-up, $F\ (2,91) = 54.02$, p < .001, $\eta^2 = .543$.

At posttest, knowledge scores were statistically greater in the high immersion condition (*M Diff* = 3.14, *SE* = .28, $p < .001$) and the medium immersion condition (*M* = 3.33, *SE* = .28, $p < 001$), compared to the low immersion condition.

Knowledge scores in the high immersion condition were not statistically different than in the medium immersion condition (*M Diff* = -.19, *SE* = .28, $p = .780$).

At follow-up, knowledge scores were statistically greater in the high immersion condition ($M = 2.86$, $SE = .342$, $p < .001$) and the medium immersion condition ($M = 3.14$, *SE* .327, $p < .001$) compared to the low immersion condition. Knowledge scores in the high immersion condition where not statistically different than in the medium immersion condition (*M diff* = -.29, $SE = .33$, $p = .660$).

There was a statistically significant effect for time of test on knowledge scores in the high immersion condition, $F\ (2, 56) = 146.88, p < .001$, partial $\eta^2 = .840$, in the medium immersion condition, $F\ (2,66) = 224.75, p < .001, \eta^2 = .872$, and the low immersion condition, $F\ (2,58) = 5.60, p < .005, \eta^2 = .162$. Means and standard deviations are presented in Table 1.

Table 1.
Means and Standard Deviations for Knowledge Scores

	Condition	Mean	Std. Deviation	N
Pretest	High	5.07	1.33	29
	Medium	5.66	1.63	25
	Low	5.40	1.63	35
Posttest	High	9.03	1.09	29
	Medium	9.34	1.03	35
	Low	6.13	1.50	30
Follow-up	High	8.65	1.29	29
	Medium	8.94	1.28	35
	Low	5.80	1.37	30

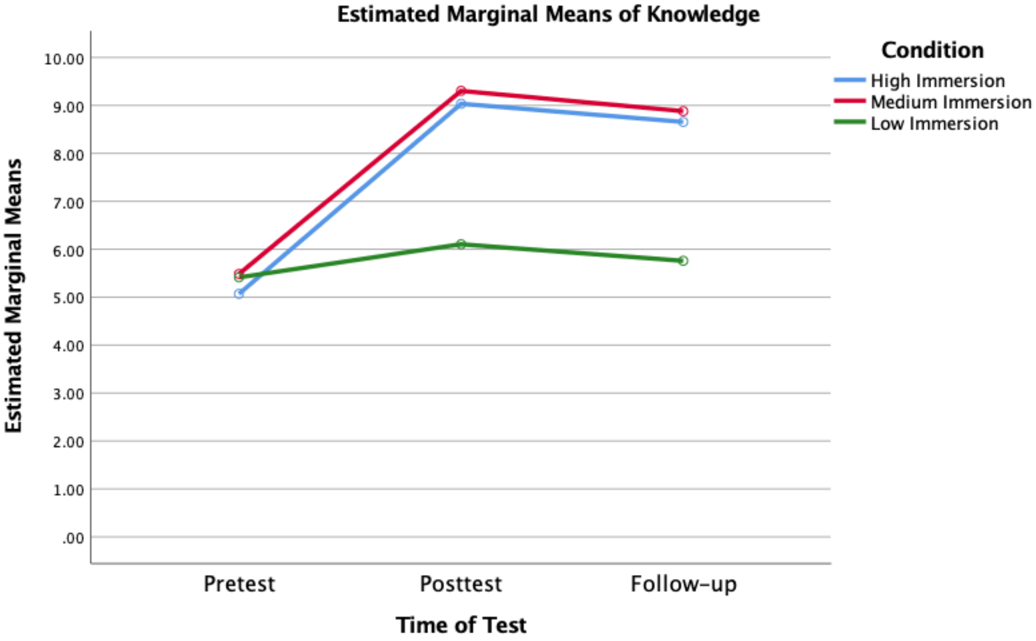


Figure 7. Plots of Means for each condition at each time of test

Presence

A one-way Welch ANOVA was conducted to determine if presence scores are different for groups with different levels of immersion at posttest. Participants were classified into three groups: high immersion (*n* = 34), medium immersion (*n* = 36), and low immersion (*n* = 37). Presence scores were statistically significantly different for different levels of immersion, *Welch's F* (2, 63.63) = 86.73, *p* < .001.

There were two outliers with studentized residual values of ±3 and both were removed. Games-Howell post hoc analysis revealed that the high immersion group (*M* = 46.26, *SD* = 5.42) scored slightly higher on presence than the medium immersion group (*M* = 46.22, *SD* = 8.15), a mean difference of .042, 95% *CI* [-4, 4], which was not statistically significant (*p* = 1.0).

The high immersion group (*M* = 46.26, *SD* 5.42) scored higher on presence than the low immersion group (*M* = 11.24, *SD* = 15.39), a mean difference of -35.02, 95% *CI* [-41.55, -28.99] which was statistically significant (*p* < .001).

The medium immersion group (*M* = 46.22, *SD* 8.16) scored higher on presence than the low immersion group (*M* = 11.24, *SD* = 15.39), a mean difference of -34.98, 95% *CI* [-41.89,-28.06], which was statistically significant (*p* < .001).

Table 2.

95% Confidence Intervals of Pairwise Differences in Mean Changes in Presence Scores

Condition	M	SD	High Immersion	Medium Immersion
High Immersion	46.26	5.42		
Medium Immersion	46.22	8.16	-3.91 to 4.00	
Low Immersion	11.24	15.40	-41.55 to 27.45*	-42.00 to 28.49*

Note: An asterisk indicates that the 95% confidence interval does not contain zero, and therefore the difference in means is significant at the .05 significance using Dunnett's C procedure.

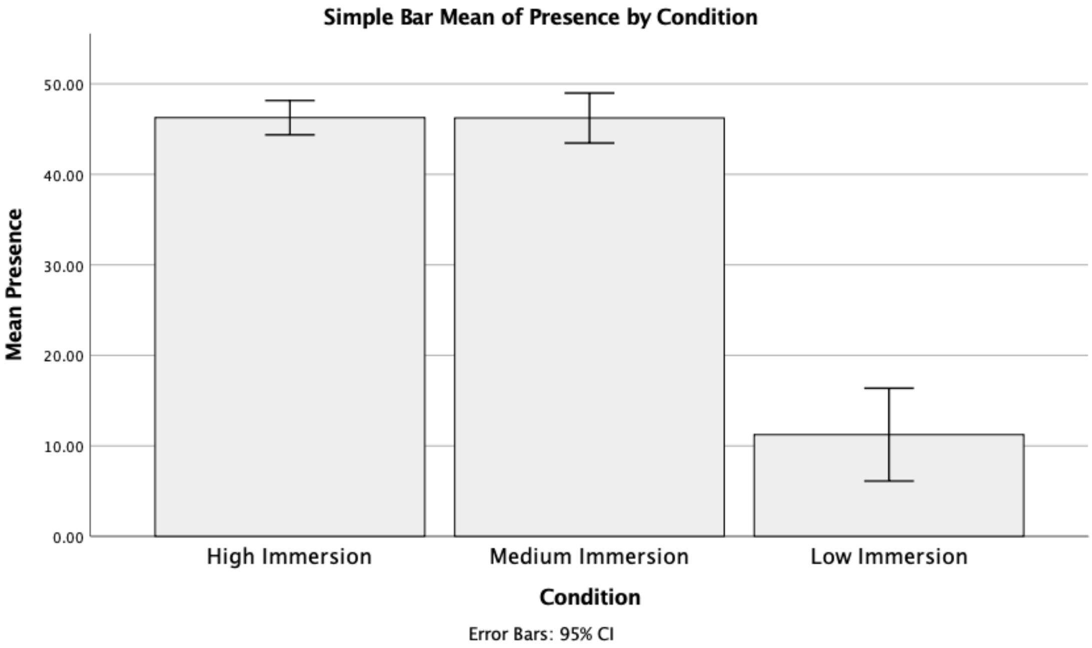


Figure 8. Plots illustrating the mean differences on Presence among the three conditions.

Cognitive Load

A one-way ANOVA was conducted to determine if cognitive load differed significantly across the levels of immersion. Participants were classified into three groups: high immersion (*n* = 34), medium immersion (*n* = 36), and low immersion (*n* = 37). There was one outlier with studentized residual values of ±3 and was removed. Cognitive load score was normally distributed for the high immersion group ($p > .07$), but not normally distributed for the medium and low immersion groups ($p < .05$), as assessed by Shapiro-Willk test. There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .280$). Cognitive load was not statistically significantly different for different levels of immersion, *F* (2,104) = 2.28, *p* = .107.

Table 3.
95% Confidence Intervals of Pairwise Differences in Mean Changes in Cognitive Load Scores

Condition	M	SD	High Immersion	Medium Immersion
High Immersion	2.85	2.35		
Medium Immersion	2.14	1.68	-1.83 to .40	
Low Immersion	1.89	1.81	-2.07 to .144	-1.34 to .84

Note: An asterisk indicates that the 95% confidence interval does not contain zero, and therefore the difference in means is significant at the .05 significance using Dunnett's C procedure.

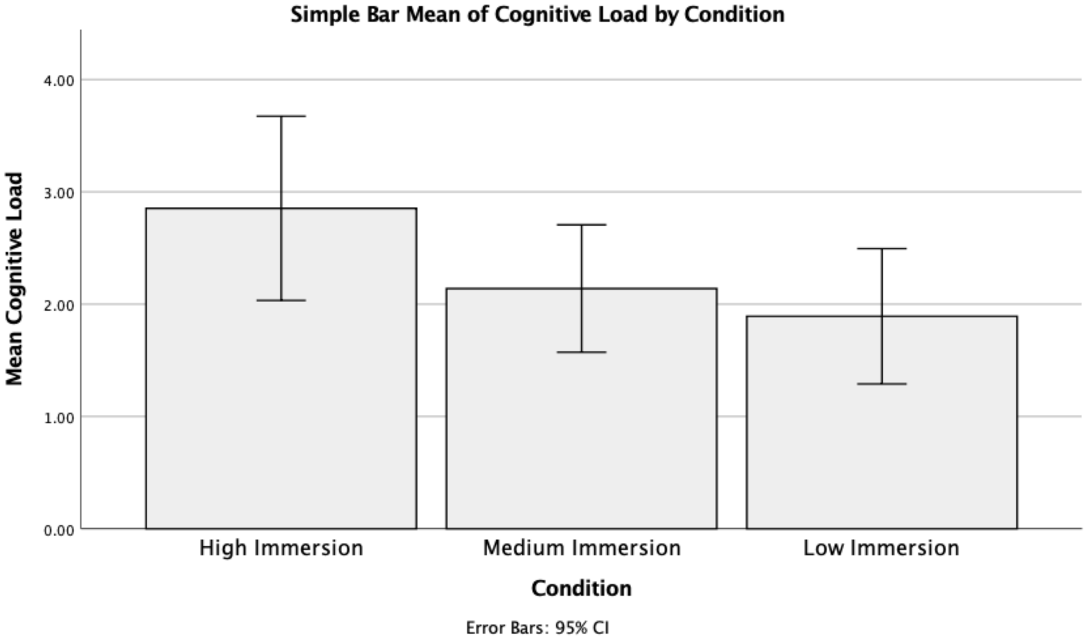


Figure 9. Plots illustrating the mean differences on cognitive load among the three conditions.

Correlations

Correlation coefficients were computed for immersion levels, knowledge scores at posttest, presence, cognitive load, and knowledge scores at follow-up. Using the Bonferroni approach to control for Type I error across the eight correlations, a *p* value of less than .005 (.05/10) was required for significance. The results of the correlational analyses are presented in the top half of Table 4. Six of the 10 correlations were statistically significant and were greater than or equal to .52. In general, the results suggest that the higher the immersion and presence, the higher the knowledge scores are at posttest and follow-up.

Partial correlation coefficients were then computed among immersion, presence, cognitive load, and knowledge at follow-up, holding constant the knowledge score at posttest. A *p* value of less than .008 (.05/6) was required for significance using the Bonferroni approach to control for Type I error across the six partial correlations. The partial correlations are reported in the second half of Table 4. One of the six partial correlations was significant and large in magnitude. The significant partial correlation assessed the correlation between knowledge at presence and immersion.

Table 4.
Bivariate and Partial Correlations (N = 93)

	Immersion	Presence	Cognitive Load	Knowledge at Followup
Bivariate correlations				
Immersion				
Presence	.71*			
Cognitive Load	.21	.08		
Knowledge at Follow-up	.60*	.52*	.70	
Knowledge at Posttest	.62*	.59*	.10	.88*
Partial correlations controlling for knowledge scores at posttest				
Immersion				
Presence	.53*			
Cognitive Load	.19	.02		
Knowledge at Follow-up	.14	.01	-.04	

**p* < .005 for bivariate correlations and *p* < .008 for partial correlations

Multiple Regression

A hierarchical multiple regression was run to determine if the addition of knowledge scores at pretest and immersion, and then of cognitive load, and then of presence improved the prediction of knowledge scores at posttest. See Table 5 for full details on each regression model.

There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.61. There was linearity as assessed by partial regression plots and a plot of standardized residuals against the predicted values. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by VIF values greater than 1. There was one studentized residual value greater than ±3 standard deviations, and it was not removed. There was one leverage value greater than 0.2 and it was not removed. There were no values for Cook's distance above 1. The assumption of normality was met, as assessed by a Q-Q Plot.

The full model of immersion, knowledge at pretest, cognitive load and presence to predict knowledge scores at posttest was statistically significant, $R^2 = .615$, $F(4,103) = 41.07$, $p < .001$, adjusted $R^2 = .600$. The addition of cognitive load to the prediction of knowledge scores at posttest (Model 2) did not lead to a statistically significant increase in R^2 of .02, $F(1,104) = .02$, $p = .887$. The addition of presence to the prediction of knowledge scores at posttest (Model 3) led to a statistically significant increase in R^2 of .057, $F(1,103) = 15.11$, $p < .001$.

Table 5.
Hierarchical Multiple Regression Predicting Knowledge Scores at Posttest from Knowledge Scores at Pretest, Cognitive Load and Presence

	Knowledge Scores at Posttest					
	Model 1		Model 2		Model 3	
Variable	B	β	B	β	B	β
Constant	2.15**		2.14**		2.01**	
Knowledge scores at pretest	.47*	.34	.47*	.34	.49*	.35
Immersion	1.73*	.70	1.72*	.70	1.11*	.45
Cognitive Load			.06	.01	.03	.03
Presence					.035*	.34

Note. N = 108. * $p < .001$, ** $p < .001$.

A second hierarchical multiple regression was run to determine if the addition of knowledge scores at posttest**,** then immersion, and then of cognitive load, and then of presence improved the prediction of knowledge scores at follow-up. See Table 6 for full details on each regression model.

There was independence of residuals, as assessed by a Durbin-Watson statistic of 2.34. There was linearity as assessed by partial regression plots and a plot of standardized residuals against the predicted values. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by VIF values greater than 1. There was one studentized residual value greater than ±3 standard deviations, and it was not removed. There was one leverage value greater than 0.2 and it was not removed.

There were no values for Cook's distance above 1. The assumption of normality was met, as assessed by a Q-Q Plot.

The full model of immersion, knowledge at posttest, cognitive load and presence to predict knowledge scores at follow-up was not statistically significant, $R^2 = .778$, $F(4,89) = 78.11$, $p = .466$, *adjusted* $R^2 = .768$.

Table 6.
Hierarchical Multiple Regression Predicting Knowledge Scores at Follow-up from Knowledge Scores at Posttest, Cognitive Load and Presence

	Knowledge Scores at Follow-up							
	Model 1		Model 2		Model 3		Model 4	
Variable	B	β	B	β	B	β	B	β
Constant	.46		.49		.42		.46	
Knowledge scores at posttest	.90*	.88	.85*	.83	.86*	.84	.86*	.84
Immersion			.20	.08	.27	.11	.30	.12
Presence					-.01	-.05	-.01	-.06
Cognitive Load							-.03	-.04

Note. $N = 108$. * $p < .001$, ** $p < .001$.

Finally, immersion groups were Helmert-coded to answer the question of whether the difference of pretest scores of the low immersion, and the average pretest scores of the medium and high immersion conditions (X1), and whether the difference of pretest scores of medium and the pretest scores of high immersion (X2) improved the prediction of knowledge scores at posttest, in addition to cognitive load and presence in the hierarchical multiple regression model. See Table 7 for full details on each regression model.

There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.84. There was linearity as assessed by partial regression plots and a plot of standardized residuals against the predicted values. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by VIF values greater than 1. There were no studentized deleted greater than ±3 standard deviations. There was one leverage value greater than 0.2 and it was not removed. There were no values for Cook's distance above 1. The assumption of normality was met, as assessed by a Q-Q Plot.

The full model of knowledge at pretest, X1, X2, cognitive load and presence to predict knowledge scores at posttest was not statistically significant, $R^2 = .31$, $F\ (4,103) = .819$, $p = .516$, *adjusted* $R^2 = -.007$.

Table 7.

Hierarchical Multiple Regression Predicting Knowledge Scores at Posttest from Knowledge Scores at X1, X2, Cognitive Load and Presence

	Knowledge Scores at Follow-up							
	Model 1		Model 2		Model 3		Model 4	
Variable	B	β	B	β	B	β	B	β
Constant	8.08*		8.08*		8.09*		8.57*	
X1	.08	.16	.08	.16	.08	.05	.02	.05
X2			-.01	-.26	-.01	.04	-.01	-.22
Cognitive Load					-.01	.09	-.01	-.01
Presence							-.01	-.13

Note. N = 108. * *p* < .001

Chapter 4

DISCUSSION

The purpose of this study was to investigate the impact of immersion on knowledge, cognitive load, and presence in a simulation designed to deliver a lesson on science lab safety training. Participants were randomly assigned to one of three conditions: high immersion (played a simulation about lab safety in a VR headset), medium immersion (played the same simulation on the computer), or low immersion (watched a video and read about lab safety procedures). Participants completed a pretest, a science lab safety training, a posttest (same as the pretest), a questionnaire with subjective presence questions, and a questionnaire with subjective cognitive load questions. Participants were again asked to complete a follow-up test (same as the pretest and posttest) a week later.

The results revealed three significant findings:

(a) Participants in the high and medium immersion conditions had significantly higher knowledge scores at posttest and follow-up than their peers in the low immersion condition,

(b) Participants in the high and medium immersion conditions reported higher presence scores than participants in the low immersion conditions.

(c) Correlation coefficients suggested that the higher the immersion and presence, the higher the knowledge scores are at posttest and follow-up.

In addition, multiple hierarchical linear regression models were conducted out of which one was significant. Limitations, implications and future directions are discussed.

Research Questions

Do knowledge scores as measured by pretest, a posttest and a follow-up differ under the different modes of immersion? Is there a relationship between the time of the test and the level of immersion? One of the significant findings of the study was that participants who learned about science lab safety under higher levels of immersion (medium or high) on average scored higher on the objective knowledge test at posttest and follow-up than from participants in the low immersion condition. Worth mentioning that participants in the high immersion condition on average scored higher than participants in the medium immersion condition, although the mean differences between the two groups are not statistically significant.

The results are consistent with the study hypothesis and with other studies in the literature that explored the impact of immersion on learning in the sciences (Coulter et al., 2007; Alverson et al., 2008; Kleinert et al., 2015). Worth noting is that levels of immersion were subjectively defined for the study. A critical assumption made before the study was that participants who experience the lab safety simulation with the virtual reality headset would experience high levels immersion, participants who experience the lab safety simulation would experience less immersion, and participants who watched the video and read about lab safety would experience even less immersion. Our immersion assumptions were partially validated by the results on measures of presence, as discussed later in this section.

Does cognitive load as measured by the NASA Task Load Index differ under the different modes of immersion? Although cognitive load measures were not statistically significantly different for the different levels of immersion, participants in the high immersion condition on average experienced the highest cognitive load in the study, followed by participants in the medium and low immersion conditions. It was anticipated that because a virtual reality environment allows for highly concrete content without separating critical information, it reduces the effects of split attention, and thus participants in the high immersion condition would experience less cognitive load.

The cognitive load measure used in the study measured the perceived mental demand, and the perceived frustration participants experienced while completing the sessions. Although participants' level of experience using virtual reality was not quantified, the lack of experience and the learning curve in learning how to use the headset and the controller may have contributed to the higher cognitive load levels.

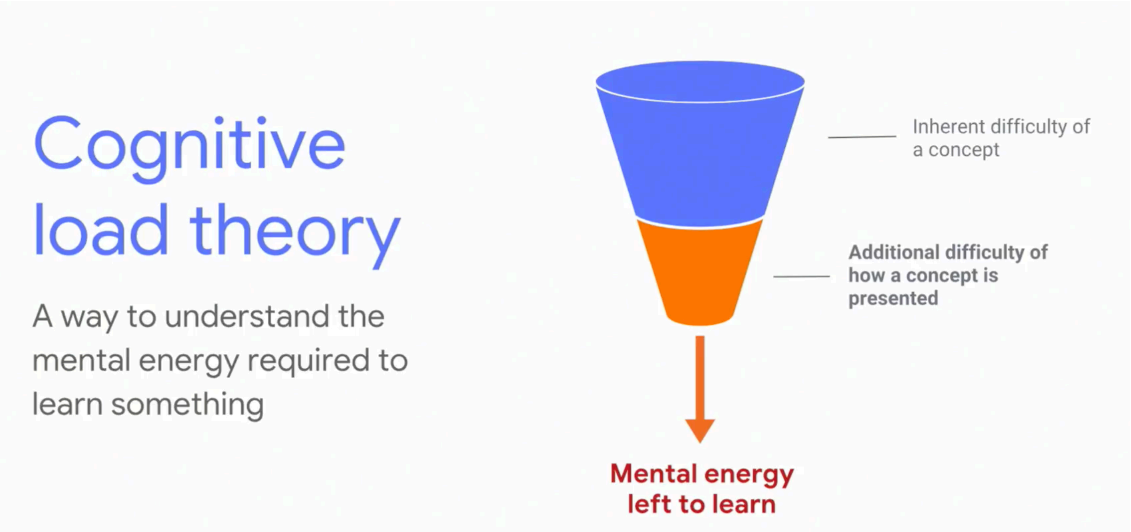


Figure 10. Overview of the Cognitive Load Theory (Google Developers, n.d.).

Future studies may consider allowing participants to become accustomed with the virtual reality headset and controller by going through the training modules VR platforms provide. For example, Oculus offers the First Contact experience (https://www.oculus.com/experiences/rift/1217155751659625/) which is designed to introduce users to virtual experience and how to use the controllers in the space.

Does presence as measured by a subjective presence questionnaire differ under the different modes of immersion? Virtual reality environments track users' movements and their surroundings as they display to the senses based on those movements. Immersion is the psychological feeling that occurs as real-world cues are replaced with digital ones, and users get lost in the space as they shut down real-world cues. Presence is the sensation of being there and a core element of a virtual reality experience.

The term 'high immersion' for participants using the VR headset was used because they were entirely removed from most of the real-world sensations while experiencing the simulation. Thus, it was hypothesized that the more removed participants are from real-world sensations, the higher the levels of presence they will report.

As expected, participants in the high and medium immersion conditions on average experienced statistically significantly higher levels of presence than participants in the low immersion condition. Surprisingly, participants in the high immersion condition reported almost identical levels of presence with participants in the medium immersion condition. Counter to the definition of immersion, participants in the medium immersion condition did not shut down real-world cues since they experienced the simulation on a computer but experienced almost identical feelings of presence with the high immersion group.

Witmer & Singer (1998) list the necessary conditions for presence: focus, involvement, and immersion. The novelty of the virtual simulation may have compelled the participants to focus at a level that contributed to increased feelings of presence. Involvement refers to how well the activity attracted and held the participant’s attention, and again, the novelty of the environment may have contributed to the feelings of presence. In addition, according to Witmer & Singer (1988), "factors that affect immersion include isolation from the physical environment, the perception of self-inclusion in the virtual environment, natural modes of interaction and control, and perception of self-movement." The combination of focus, involvement, and the factors that affect immersion, sans the isolation from the physical environment, may have been enough to elicit feelings of presence, similar to the participants in the high immersion condition. Future studies should focus on identifying specific factors that influence feelings of presence in non-VR virtual environments.

Table 8.
Average agreement with the statement "How aware were you of events occurring in the real world around you?" (0 = not at all; 6 very)

Condition	How aware were you of events occurring in the real world around you?
High Immersion (n = 35)	2.11
Medium Immersion (n = 36)	3.36

Are there significant correlations between variables? Can knowledge scores be predicted from the independent variables? The results of the correlational analysis suggested that the higher the immersion and presence, the higher the knowledge scores were at posttest and follow-up. Also, the addition of presence to a multiple regression model improved the prediction of knowledge scores at posttest, although the effect of presence seemed to diminish and did not improve the prediction of knowledge scores at follow-up. These results were confirmed by the second hierarchical regression model where the knowledge scores at posttest had the only significant effect. Participants in the low immersion group watched the video and read the information about lab safety, and did not participate in an engaging simulation like the participants in the medium and high condition. The passive activity of watching the video may have not elicited feelings of presence as participants did not have any control of the events in the video (control), were not shut-off from real-world cues (distraction) and did not experience any degree of realism (Wilmer & Singer, 1998).

The results of the third hierarchical multiple regression model show that the differences on knowledge scores at pretest among the high and medium immersion conditions when compared to the low immersion condition did not improve the prediction knowledge scores at posttest. The addition of the differences on knowledge scores at pretest between the high and medium immersion conditions, cognitive load and presence did not improve the prediction of knowledge scores. The differences between the two groups were the interactive nature of playing the simulation versus the passive nature of watching the video and reading the text.

This may suggest that, if everything else held constant, interactivity may have not been a predictor of knowledge scores, inconsistent with the literature on embodied cognition that the motor system influences our cognition. Future studies of controlling for interactivity within virtual environments may be beneficial to further understand the impact of interactivity in virtual reality environments (for example, learning in 360-degree video versus a virtual simulation).

The literature on immersion, presence and task performance is limited, and the results of the correlational analyses are contrary to Mania and Chalmers (2000) who did not find presence to be correlated with the task performance of acquiring knowledge during the lecture. Also, Parong and Meyer (2018) who found that students who reviewed a self-directed slideshow on a desktop computer performed statistically significantly better on the posttest than a group of students who participated in the equivalent lesson in virtual reality. Worth noting that even though Parong and Meyer did not find a relationship between immersion and knowledge scores, participants in the VR group reported higher motivation, interest and engagement ratings.

Motivation, interest, and engagement may be essential factors in learning environments, especially in distance programs (Moore, Bartkovich, Fetzner, & Ison, 2003). This study did not address those factors, something that future studies should. Student retention in online learning environments is an issue, and distance learning programs may address student motivation, interest and engagement through offerings in virtual reality. The issue of retention and interest in STEM degrees is also amplified (Watkins & Mazur, 2013), and the introduction of learning activities using virtual environments may help remediate the issue and improve interest in the field.

Conclusions

The potential of virtual reality simulations and their broader use in education has been explored throughout the years. Virtual reality simulations have been used in subjects such as medicine, science, social work, and psychology, but limitations in computing and high prices led to limited access to hardware and adoption of virtual reality simulations in education. Recent advances in computing have enabled platforms like Oculus and Daydream to produce hardware at prices that are accessible to consumers and enabling a wider consumer adoption. Companies like Labster have been experimenting with making their simulations available in VR, allowing universities to adopt the software in their curriculum. Despite recent advances, there is little evidence of virtual reality's use as a mainstream educational tool.

The motivation for this study was to attempt to understand the practical implications of teaching science to college students using virtual reality. For example, a standard way of presenting materials to online students is by using video, text, and images embedded in the LMS. Virtual simulations could effectively replace this practice and instead be used to teach science subjects with better results for students. Even though the study's scope was limited to one simulation and on one topic, the results were promising, and future studies are encouraged to try to replicate the results with other subjects.

Results showed that participants who learned the subject in simulations had significantly higher knowledge scores at follow-up than their peers who learned about the topic by watching a video and reading relevant text. A potential future direction for the study would be to design a study where participants learn a subject using a virtual simulation, and then they apply their knowledge in a real-life situation. For example, a follow-up to this study would be to assess participants' understanding by asking them to demonstrate safety procedures in a physical science lab.

Results also showed that participants who learned the subject in simulations reported higher measures of presence than participants who learned about lab safety by watching a video and reading relevant text. The potential implications of educational experiences that elicit high feelings of presence have yet to be explored, especially within the context of distance learning. Retention is an issue in distance learning and designing and deploying educational experiences that support motivation and engagement could be beneficial for students in these programs. Results did not show significant differences in presence measures between the two simulation conditions (VR vs. desktop) and future studies should try to explore this in more detail: if the same result can be achieved with a desktop simulation, why would users be asked to experience the same simulation in virtual reality?

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APPENDIX

APPENDIX A IRB APPROVAL

ASU Knowledge Enterprise Development

APPROVAL: MODIFICATION

Brian Nelson
Division of Educational Leadership and Innovation - Tempe
480/727-4550
Brian.Nelson@asu.edu

Dear Brian Nelson:

On 9/12/2018 the ASU IRB reviewed the following protocol:

Type of Review:	Modification
Title:	Teaching Lab Safety Digitally: Exploring How Virtual Simulations Affect Learning
Investigator:	Brian Nelson
IRB ID:	STUDY00008401
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• savvides_recruitment_letter_2.pdf, Category: Recruitment Materials; • irb_pre_post_test.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • HRP-503a-TEMPLATE_PROTOCOL_SocialBehavioralV02-10-15_2.docx, Category: IRB Protocol; • savvides_short_consent_2.pdf, Category: Consent Form; • irb_task_load_index.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • irb_savvides_presence_questionnaire.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);

The IRB approved the modification.

When consent is appropriate, you must use final, watermarked versions available under the “Documents” tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Philippos Savvides

APPENDIX B

KNOWLEDGE TEST

1. Which symbol depicts an oxidizing reagent?

2. What does the following symbol mean?

a. Health hazard
b. Toxic
c. Corrosive
d. Harmful

3. Why don't you clean a spill with water?

a. The acid reacts with water
b. It would pollute the water
c. The acid freezes the water
d. It could ignite

4. Why is it dangerous to wear contact lenses in the lab?

a. Liquid can be trapped under them
b. The plastic reacts with acids
c. Glasses protect better than lenses
d. They don’t protect well enough

5. What do you have to do if there is an unexpected violent chemical reaction in a bottle?

a. Evacuate
b. Add water
c. Add baking soda for neutralization
d. Close the lid of the bottle

6. What should NOT do if a person’s clothes suddenly catch fire?

a. Wrap a fire blanket around a standing person
b. Splash them with a bucket of water
c. Drag them under a safety shower
d. Stop them and smother the fire by rolling them on the floor

7. There are usually two different types of fire extinguishers: CO2-based, and foam based extinguishers. Why should you never use a CO2 based extinguisher on a person?

a. CO2 is freezing cold
b. CO2 is corrosive
c. CO2 is toxic
d. The person would suffocate

8. What is the first thing you have to do if there is a fire in the lab?

a. Alert people
b. Open the windows
c. Splash the fire with water
d. Run for the fire extinguisher

9. A compressed gas container can explode if:

a. Heated
b. Dropped
c. Flammable gas is released near an ignition source
d. All of the above

10. Which of the substances below is the most corrosive based on their pH value?

a. pH 7
b. pH 8
c. pH 6
d. pH 0

APPENDIX C

COGNITIVE LOAD QUESTIONNAIRE

		Not at all						Very
1.	How mentally demanding was the task?	0	1	2	3	4	5	6
2.	How insecure, discouraged, irritated, stressed and annoyed were you?	0	1	2	3	4	5	6

APPENDIX D

PRESENCE QUESTIONNAIRE

		Not at all						Very
1.	How much were you able to control events?	0	1	2	3	4	5	6
2.	How responsive was the environment to actions that you initiated?	0	1	2	3	4	5	6
3.	How natural did your interactions with the environment seem?	0	1	2	3	4	5	6
4.	How aware were you of events occurring in the real world around you?	0	1	2	3	4	5	6
5.	How compelling was your sense of objects moving through space?	0	1	2	3	4	5	6
6.	Were you able to anticipate what would happen next in response to the actions that you performed?	0	1	2	3	4	5	6
7.	How compelling was your sense of moving around inside the virtual environment?	0	1	2	3	4	5	6
8.	How closely were you able to examine objects?	0	1	2	3	4	5	6
9.	How well could you examine objects from multiple viewpoints?	0	1	2	3	4	5	6
10.	How well could you move or manipulate objects in the virtual environment?	0	1	2	3	4	5	6