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The Long-Term Effects on Conceptual Change and Affect for Preservice Teachers One Year After a Cave Automatic Virtual Environment (CAVE) Experience

By

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B.S., Simmons College, 2013

PLAN B PROJECT

Submitted in partial fulfillment of the requirements
For the degree of Masters in Science in Natural Science & Environment and Natural Resources
in the Science and Mathematics Teaching Center at the
University of Wyoming, 2018

Laramie, Wyoming

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Abstract

The current research evaluated the long-term effects of a cave automatic virtual environment (CAVE) experience on preservice teachers' conceptual change and affect. To evaluate the lasting effects, four students from a physical science class were interviewed one year following their experience in a CAVE simulation in which they learned about molecular density. For each participant the interview produced a transcript of his/her spoken responses and a drawing that was compared to the drawing s/he had done the year before. The results of the research showed that participants manifested both positive and negative affect in regard to their CAVE experience. Positive affect was most common in recalling the CAVE experience itself, while negative affect was most prevalent when recalling specific content learned. All four participants retained changes in conceptions from their time in the CAVE. However, these conceptual understandings consisted of both accurate information and misconceptions.

Cheers, to the wild people and places that inspire and encourage

Acknowledgments

This Plan B project would not have been possible without the experiences afforded to me by the Teton Science Schools and the Science & Math Teaching Center over the last two years. Special thanks go to my Chair, Dr. Alan Buss, who provided me with the kind of calm and mentorship that a student can only hope for. Last but not least, I could not have done this without my family and friends, especially my father. Thank you so much.

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Chapter One: Introductions

Background

One winter morning in 2017, I came into my graduate class, “Advanced Instructional Strategies”, to find pieces of paper and a drinking straw on the table where I sat. As I surveyed the room I noticed that this was true of all the tables. The faculty who was leading the course waited until everyone was sitting down to prompt us with the question, “If you fold one of the pieces of paper in half and then blow through your straw between the two sides, what will happen? Take a moment to write down what you think, using both drawings and words. Once you have it down, share with your table what you believe will happen.”

I stated that the two sides of the folded paper would blow up and away from the stream of fast moving air coming from the straw. My classmates believed similar things, with some slight variation. However, when we tested our hypotheses, we realized that we had it all wrong. The paper became concave, as it moved in towards the fast-moving air. We were then prompted to record, using both pictures and writing, what we actually observed happening. This activity was followed by a series of similar activities on air pressure, each one making me realize just how unaware I was of the physical world. This series of activities taught the class about high and low air pressure, and eventually basic flight. However, the purpose of our morning activities was actually to introduce the Conceptual Change Model as developed by Dr. Joseph Stepan (2003).

This was the first time I had considered conceptual change as a teaching strategy and was interested in Dr. Stepan’s approach to facilitating it. I am driven by environmental and social issues and was struck by what an amazing tool this strategy could be for informing the public understanding on things such as climate change and land management. I began brainstorming ways to incorporate the ideas of conceptual change into my graduate research and decided that

the best way to gain expertise on this topic would be to begin with issues that were not as politically charged.

Upon arriving at the University of Wyoming I was introduced to Dr. Alan Buss, who was researching conceptual change in relation to student experiences with a digital Interactive Virtual Environment Technology (IVET) that provides students the opportunity to interact with virtual water and oil molecules. Although not entirely in line with my long-term interests, it seemed like the perfect way to gain a better understanding of the theories of conceptual change and how it is best applied. Using Dr. Buss's latest research, I was able to identify an opportunity for a longitudinal pilot study that assessed conceptual change.

Conceptual change is an ongoing learning process involving the reconstruction of misinformation, misunderstandings and missing information. Often students are not aware that these gaps exist as they enter into the learning experience, and if they not addressed they become the flawed foundations of understanding on which students make sense of new information. However, when conceptual change occurs misconceptions are exposed while giving students the experience they need to build correct frameworks. Learners are most successful when they feel empowered to use this process to fill in these gaps in understanding long after their facilitated learning experiences have concluded (Vosniadou, 2013).

While *conceptual change* is a popular term among educators today it has been circulating since the early 1960s, when it was coined by Thomas Kuhn (1962). At that time, the idea focused on how scientific theories are constantly changing and how people must work hard to keep their conceptions up to date. It was not until 1982 that Posner et al. began to discuss the importance of this idea in regard to how science is taught to students. In educational research, conceptual change is almost always paired with a specific subject area. From mathematics to atomic

structures, a topic of learning is identified in order to measure the conceptual change that occurs (Vosniadou, 2013).

Connections between technology and conceptual change have been evaluated in many recent studies. Results from these studies show that there are increases to conceptual changes on a topic when students use tools of technology to guide their learning experiences, compared with more traditional classroom techniques (Liao, 2009; Chen, Sung, & Change, 2013). Furthermore, studies have shown that learning is increased and skills are attained more efficiently when that technology is a three-dimensional (3D) virtual experience, compared to learning on a two-dimensional (2D) screen (Gruchalla, 2004).

The 3D experiences in Gruchalla's study (2004) were facilitated by the creation of digital immersive virtual environment technologies (IVETs), much like the one in Dr. Buss's current research, from which this study is associated. The idea for creating these sorts of digital technologies first began in 1963, with the vision of one computer programmer, Ivan Sutherland. However, it has taken many years for the available technology to catch up with the vision for creating these immersive environments. Now that the technology is available, and improving constantly, it will be very interesting to see what the future looks like for these simulations (Blascovich & Bailenson, 2005).

This study aimed to evaluate the subjects' affect in response to their learning experience. Immordino-Yang (2011) found that the emotions involved in a learning experience are strongly related to the level of learning that takes place. This is a mechanism of social, emotional, and motivational factors related to student engagement in a learning experience. Depending on the emotion that a student embodies at the time of learning, their outcomes can be altered. If an awareness of this connection to affect exists, outcomes can be better controlled. For example,

fear results in the intuition for a student of needing to flee from a situation. This results in diminished learning when compared to the learning of a student who felt happy throughout the same experience, as happiness allows for students to be receptive to others and ideas, an important mindset for learning (Immordino-Yang, 2011). Depending on what affect is experienced by students, interesting connections and explanations can be drawn concerning this IVET as an effective teacher tool.

Problem

There is little to no evidence available to explain the long-term impacts of Digital IVET on student conceptual change and affect. This is a problem because, although there is evidence to support that conceptual changes are happening (Ahn, Bailenson, & Park, 2014; Liao & She, 2009; Chen, Pan, Sung & Chang, 2013). there is little known whether those changes are retained by the students after they have moved on from the immediate experience. There is also little known about what the lasting impacts are to the student's affect in recalling their time interacting with these learning tools. Harboring positive affect in a learning environment increases engagement (Immordino-Yang, 2011), however evidence of long-term impacts is needed to uncover the utility of these technologies as a useful teaching tool in regard to conceptual change and affect.

Research Question

What are some of the lasting effects, one year after an IVET experience, both in regard to conceptual change and affect, for a small group of preservice teachers observing the molecular phenomena of density?

Purpose

This study investigates whether there are connections between lasting student conceptual change and affect vs. experience with the IVET. However, the purpose of this study was not only to produce conclusions on the effectiveness of this technology, it was also meant to serve as a pilot for further research on this issue. An overview of the most recent literature, an analysis of research findings, amendments to the research methods, and research questions for future study will be the product of this work.

Chapter Two: Literature Review

Conceptual Change

Conceptual change was first coined in 1962, by Thomas Kuhn. However, several decades passed before it gained the meaning it holds today. Conceptual change can be defined as the reorganization of knowledge as a means for: recognizing facts in a broader context, reworking flawed or incomplete frameworks, and building a scientific literacy to approach scientific topics in the future (NRC, 2008). However, as conceptual change has evolved, so has its utility, moving it from a strictly science focus, to a more holistic application for topics such as social issues (Lundholm & Davies, 2013), history (Carretaro, Castorina, & Levinas, 2013), and mathematics (Vamvakoussi, Vosniadou, & Van Dooren, 2013) (Vosniadou, 2013). This section will introduce conceptual change by exploring the three types as introduced in *Ready, Set, SCIENCE* (NRC, 2008), two approaches for how it is best implemented, and a model for facilitation (Vosniadou, 2013; Stepan, 2008).

Types of conceptual change. As the given definition of conceptual change suggests, this is a multidimensional topic. Many kinds of conceptual change exist, and the level of difficulty for implementation varies. Outlined below are three types of conceptual change, in order from the easiest to the most difficult to implement (NRC, 2008).

1. *Elaborating on Preexisting Concepts:* This type of conceptual change occurs when the teacher builds upon a preexisting and accurate framework that the students already have. This is relatively easy to accomplish. As new information, in the forms of evidence and experience is introduced, students use it to build on what they already know, without discrediting any of their preconceived notions.

2. *Restructuring a Network of Concepts:* Slightly more difficult to achieve than the previous, this type of conceptual change involves students changing the way they think about a topic, which usually involves them leaving behind an old way of thinking. The level of difficulty involved in changing student conception is determined by how attached they are to their original ideas. As an example, when students consider that a gas, a liquid, and a solid are not mutually exclusive but are instead different phases of the same thing. Students may have to acknowledge that what they thought before was inaccurate and move forward with a new understanding.
3. *Achieving New Levels of Explanation:* This third type is identified as the hardest type of conceptual change because it involves making connections beyond the topic itself, while also having to rework baseline understandings. An example of this is my own experience in learning about air pressure. Once my class grasped the concepts of high and low air pressure, we then used our new knowledge to explain the flight of birds and planes.

The phenomenon of conceptual change is therefore happening whenever new evidence or experiences is accessed, which then either builds upon what is already known or reworks an understanding that was incomplete or flawed. Yet, how to best achieve conceptual change is the biggest question facing this field of research.

Two approaches to conceptual change. The *classical approach* to conceptual change, which suggested a replacement of information during an isolated event, is now considered to be outdated. Initially, it was critical in the evolution the understanding of conceptual change and must be considered in the discussion. This approach posits that in order for a student to undergo

a change in conception, the following must be true (Vosniadou, 2013): “(1) dissatisfaction with existing conceptions, (2) there must be a new conception that is eligible, (3) the new conception must appear to be plausible, and (4) the new conception should suggest the possibility of a fruitful program” (pg. 11). However, this approach strictly focuses on the facilitation of students undergoing cognitive conflict. Meaning, that a student must experience the error of their original thinking in order for conceptual change to happen (Vosniadou, 2013). Yet, as the three kinds of conceptual change demonstrate, the phenomenon of conceptual change is not that simple or limited (Michaels et al., 2008). This shortcoming may explain why a new approach has been identified.

In the most recent edition of the “International Handbook of Research on Conceptual Change”, Vosniadou (2013) opened the book by introducing the *Framework Theory Approach*, as the most current understanding of how conceptual change occurs. Seemingly, a large conceptual change occurred among those most immersed in studying it, when they became dissatisfied with the classical approach. As a result, they began developing something more demonstrative of the phenomenon they were researching. The major reasons they became dissatisfied with the classical approach are as follows. (a) Misconceptions were seen as totally false and not as potential fragments of ‘the true story’; (b) Cognitive Conflict was seen as the only path to conceptual change; (c) The classical model did not take into account the ongoing process of learning and instead suggested sudden shifts in understanding. Although simplified, these three issues are the identified drivers for the creation of the framework theory approach (Vosniadou, 2013).

The framework theory approach was based on the understanding that, “young children start the knowledge acquisition process by developing naïve physics that do not consist of

fragmented observations but form a relatively coherent explanatory system- a framework theory” (Vosniadou, 2013, p. 13). The framework is used by students to organize everything else that they come in contact with. These frameworks, for most people, are built on a set of *naïve physics*, a term used to describe the incomplete understandings we use to explain how the world works. An example of naïve physics is the concept of density. People often understand the role of mass or volume, but not the relationship of the two (Stepans & Renner, 1982). People do not understand that they are carrying false or incomplete information, because the brain has successfully filled in the gaps of understanding, creating an explanation supported not only by what they think they understand, but by their personal experiences. These understandings, or naïve physics, are also referred to as *mental models* (Vosniadou, 2013).

The solution however, is not to try and change these mental models instantaneously. Instead the framework theory approach calls for a reworking of our schooling curricula in order to “reduce the gap between students’ expected initial knowledge and the to-be-acquired information...” (Vosniadou, 2013, p. 27). This strategy will allow for students to continue using new knowledge as building blocks to be added to what they already know. The framework theory approach also calls for a restructuring of how students learn. Vosniadou (2013) shares that students must build on their “metaconceptual awareness, epistemological sophistication, hypothesis testing skills, and the top-down, conscious, and deliberate mechanisms for intentional learning...” (p. 27). In other words, students need to realize that their mental models should always be open for critique and change, they should be eager to put what they “know” to the test, and they should not passively take-in information, but instead be an active participant in the process.

A model for conceptual change. The Conceptual Change Model (CCM) was published by Dr. Joseph Stepan for the first time in the early 2000's. The model is a six-stage, activity-based process, designed to facilitate conceptual change amongst students. The six stages are as follows: (a) Expose what they think about the topic prior to the activity; (b) Share these beliefs publicly; (c) Test these beliefs through hands on experience; (d) Compare what happened to what they thought would happen and try to explain any differences observed; (e) Draw connections between what they observed and other real-world phenomena; (f) Continued exploration. The end goal is to replace misconceptions with new and accurate understandings (Stepans, 2008).

Stepan's (2008) CCM is heavily rooted in the classical approach, which could support arguments against its utility, however I would argue that it is still a relevant model for facilitation. CCM still facilitates a meaningful process that supports the framework approach, but only one isolated step of the larger process. I agree that this new approach does inform CCM, but only as far as to redefine exactly what it accomplishes. For example, instead of claiming that the model replaces misconceptions, the claim is now that it facilitates the reworking of students' frameworks, contributes missing pieces that help inform stronger mental models and encourages continued exploration of the concepts.

The latest research on Conceptual Change calls for a reworking of how students learn, which will first require a shift in how they are taught. The intention is that students who are equipped with the understanding that education is an on-going process. To elaborate, the target is the development of students who view themselves as life-long learners who are ready to challenge their conceptual understanding of the world.

Affect

What do students need before they can be successful in school? It is easy to jump to things like technology, or hands-on experience to answer this question. However, the answer begins at a more basic level, which is that they need positive affect (Immordino-Yang, 2011). In other words, what are students feeling? Do they feel safe? Do they feel confident? To describe

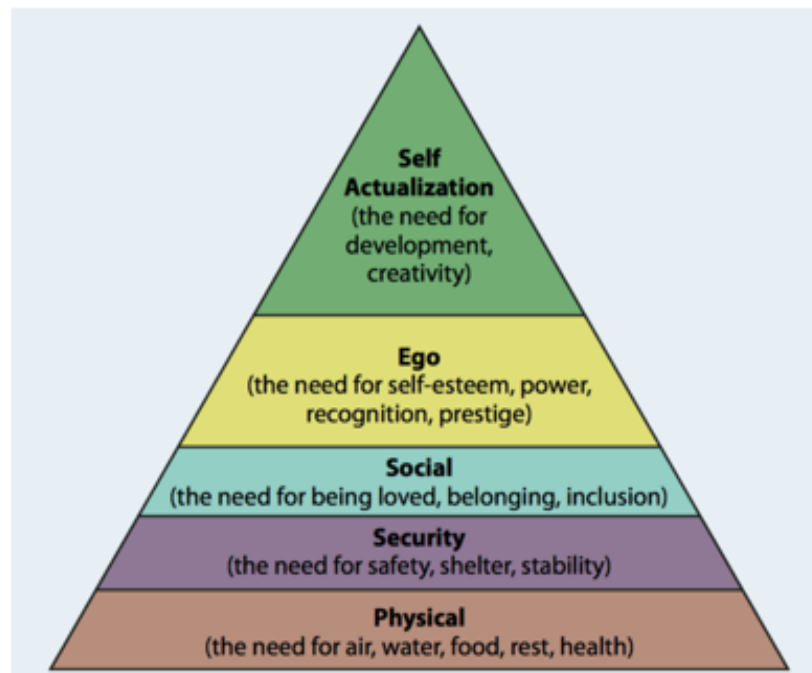


Figure 1. Maslow's Hierarchy of Needs organized in pyramid. The most basic needs are towards the bottom, and the more complex needs towards the top.

affect, this section will provide an overview of Maslow's hierarchy of needs, a discussion of body language as an indicator for student affect and conclude with evidence of affect's impacts on education.

Maslow's hierarchy of needs. Maslow first published his idea in 1943, by describing the five basic needs of people. Although the original work was published over seven decades ago, this theory remains one of the leading models in understanding the foundational needs of all

people. The five needs were organized in a pyramid (Figure 1). The base of the pyramid is the most basic of needs; at the top, the more complex. However, all five needs are considered fundamental, because they all must be achieved in order for a person to be a truly active and engaged citizen or student. This is determined by a person's ability to motivate for reasons other than their own basic needs. The needs are described as follows (Maslow, 1943).

- *The Physiological Needs:* These needs consist of the most basic, including food, water, air, and other crucial essentials such as electrolytes and calcium. Maslow explains that to try and name all of these needs would be never-ending. So, he instead characterized them as the needs that would dominate a person's every thought, and their actions, if they were not met. In other words, a person's only motivation is to obtain these needs. Only once a person has met their physiological needs, can they then begin to attain the next level of the pyramid.
- *The Safety Needs:* Although seemingly self-explanatory, once safety needs are realized, they instantly become the most important thing on a person's mind, as long as their physiological needs are met. Things such as injury, illness and imminent danger priorities. Maslow explains, that humans can be considered "safety seeking organisms", meaning they will go to whatever means necessary to feel safe. Most of these needs are achieved simply by living in human society, where murder, robbery and death by wild animal is not on the forefront of a person's mind. Once that state of safety is realized, the next level of Maslow's pyramid can be considered, however as soon as safety becomes a concern again, a person returns to this level.
- *The Love Need:* These needs consist of a person's desire to feel love, affection and belonging. Humans are social beings, and this need exposes the importance of

community and family. This need includes both the act of giving and receiving love, however it should not be confused with act of sex, which is better described by a person's physiological needs, claims Maslow. Without the feeling of love, a person's motivations will be strictly focused on obtaining it.

- *The Esteem Needs:* Once a person feels that they give and receive love adequately, they will then begin to focus on their self-esteem. Maslow explains that almost every human has the need for self-respect, which they gain through self-perceived achievement and respect from others. From this self-esteem comes a feeling of self-worth. However, if this need is neglected, a person can be lead to self-deprecation and insecurity. Yet, only with a feeling of good self-esteem can a person reach the peak of Maslow's pyramid.
- *The Need for Self-Actualization:* This need is defined as a human doing what they feel they should be doing. Maslow explains, that an artist will not be happy if she is not doing art, and musician will not be happy if he isn't doing music, etc. Although defined as a basic need, self-actualization is not easily obtained. Those that have reached this level of the pyramid are, in fact, the exception. Yet, it is only after a person has obtained all five basic needs, that they can become their most motivated in creativity and productivity.

Although Maslow (1943) introduces his theory in a very static way, he was the first to admit, that this theory actually represents a fluid and dynamic system. In this system, people may move up and down the pyramid as progress upwards towards self-actualization. Regardless, it is clear that as people are asked to learn and produce in society, they must first obtain their basic needs. To answer the question posed earlier - this hierarchy is what students need in order to be successful in school (Kee-Smith, 2006)

Body Language. The solution for solving issues with student affect has yet to be defined. Furthermore, students who need the most help, will often not vocalize that they are even having a problem (Kee-Smith, 2011). However, 55% of people communicate to each other comes not from what they say but from their bodily expressions (Yang, 2017: Patel, 2014). Interpersonal communication can be summed into two types of communication, verbal and non-verbal, so if only the spoken word is considered, an incomplete understanding of what is being communicate results, especially in regard to how they are feeling (Gelder, 2006). This has implications for teachers in classrooms, both in reading their students' affect and in how they carry themselves. For example, a learning environment can be improved if a teacher has good eye contact, and an open demeanor, while keeping an eye out for the non-verbal signals from students who seem to be suffering from poor affect and addressing these students when these signals are identified (Yang, 2017).

The idea of body language is not new. In ancient Greece, body language was a focal topic in research (Gelder, 2006; Patel, 2014). Darwin also studied the topic and made the observation that physical reactions within organisms occur because they heed some benefit for that organism. This has implications for body language as well. The benefits for people's non-verbal expressions are largely in the form of improved communication and relationship building, which is paramount in this socially-driven world (Patel, 2014). However, understanding body language is complicated, as the body can perform 700,000 different movements, which makes comprehension rather complex. Furthermore, when a person's body language is processed the following features are all considered simultaneously: Facial expressions, eye contact, body gestures, body postures, silence, head motion, proxemics, haptics, and appearance. In gaining a

stronger grasp on the role of body language and how to best decipher its meaning, the affect of others, including research participants and students, can be better understood.

The impact of affect in education. Maslow's hierarchy has been shown to play a crucial role in education (Kee-Smith, 2006; Maslow 1943; Fisher and Royster, 2016). Students often do not feel safe, loved, and self-confident in the classroom, which results in poor affect, and ineffective learning environments (Kee-Smith, 2006). The connection between how we are feeling emotionally and how well we are able to learn, is continuously supported by research (Saxbe, Yang, Borofsky, & Immordino-Yang, 2012). One example is the relationship between students' emotional state and their cognitive ability, as a result of the impacts that their emotions are having on their bodily function, e.g. rise in blood pressure can hinder academic performance. This means that the body's physical condition is playing a vital role in the learning process (Immordino-Yang, 2011); a finding that further supports Maslow's claims.

Social and cultural constructs also impact what a person feels, believe, decide, their body's well-being, and therefore what they are able to learn. A student who is considering their reputation in a classroom, and is afraid of looking stupid, or spurring confrontation, is not going to feel safe, and if s/he does not feel safe, s/he is struggling at the bottom of the hierarchy. At this point, students usually go into "fight or flight mode". This is not conducive to students doing their best learning (Immordino-Yang, 2011). When these sorts of crises are going on in a student's head, chances are s/he is also showing physical signs (Petal, 2014), which allow for issues to be addressed if they are recognized (Yang, 2017). Unfortunately, these signs are more often ignored, and students may drop out of school because of negative affect (Kee-Smith, 2011).

Teaching Molecular Density

Students of all ages and ability are often unable to understand natural sciences key concepts (Pearsal, Skipper, & Mintzes, 1997). However, misconceptions and confusion are important parts of the learning process. It is when these misconceptions go unaddressed that issues arise, which seems to be what is occurring. Even teachers often struggle with these same key concepts, which can result in deeply engrained incomplete and inaccurate understandings (Stepans, 2003). In fact, most preservice teachers fail to understand even some of the most basic scientific concepts, e.g. density. This means, that as these pre-service teachers begin in a classroom of their own, their misconceptions are passed down to the next generation of students.

A recent study looked at 277 senior level pre-service teacher one month before graduating. All the teachers took a test to assess their understanding on what sinks and what floats in water. The test looked at four categories (a) Lack of knowledge; (b) Lack of scientific knowledge; (c) Lack of confidence; (d) Misconceptions. This study showed that teachers were uncomfortable with the subject matter in all four categories. It also revealed that most of these pre-service teachers believed they understood density, but they did not. In most cases participants turned to weight as the determining factor of whether an object would sink or float-not density. Participants also held misconceptions concerning displacement, buoyant force, and pressure force (Kiray, Aktan, Kaynar, Kilinc, & Gorkemli 2015).

These studies on learning about the concept of density are interesting, as they expose a barrier to meaningful conceptual change. Even if teachers master the art of facilitating student learning and development, without accurate mental models, it is difficult for students to move

forward with correct frameworks. This leads to the discussion of recent educational tools that are facilitating more a more accurate understanding and more effective conceptual change.

Digital Immersive Virtual Environment Technologies (Digital IVETs)

Current research is evaluating the effectiveness of a specific Digital IVET called the Cave Automatic Virtual Environment (CAVE). Using a custom computer program, 3D images of molecules are projected on the walls and floors of a small room. Students are able to be in the room and interact kinesthetically with molecules of different liquids at different temperatures and explore the concept of molecular density. Due to the role that this technology plays in the current research, I will provide a short overview of Digital IVETs and their application in education.

Immersive Virtual Environments (IVEs) are described as “an organization of sensory information (e.g., the simulation) that leads to perceptions of a synthetic (artificial) environment as non-synthetic (real)” (Blascovich & Bailenson, 2005, p. 230). The addition of the word “technology” to the end of this term (IVET) communicates the that tool makes this artificial environment feel real, rather than the experience itself. The addition of the term ‘digital’ (Digital IVET) communicates that the experience is created using computer technologies. These are important distinctions, as IVEs alone can be created using nothing more than simple tools such as a made-up story line, or hammers and nails, as they are simply situations that allow a person to step into an alternate reality. Relatively recently, these tools have become digital. Computer programmer Ivan Sutherland had the vision to create simulations like this as early as 1963, yet the available digital technologies only allowed for very simple experiences. Technology has become even faster and is getting faster every day. Faster digital IVETs mean more realistic virtual experiences (Blascovich & Bailenson, 2005).

As digital IVETs improve, the application for them diversifies. In line with the current research, several studies have reported findings that show an increase in students' performance and understanding of a given topic when an IVET is used, compared with traditional classroom-based lecture and instruction (Liao & She, 2009; Chen, Sung &, Chang, 2013). One study even showed higher long-term retention of conceptual changes and scientific reasoning when an IVET was employed (Liao & She, 2009). In addition to the use of IVETs in educational research (Friena & Canessa, 2015), research involving their utility in criminal justice (Blascovich & Bailenson, 2005), environmental behavior (Ahn, Bailenson, & Park, 2014) and false memory (Segovia & Bailenson, 2009) has also been evaluated. For example, one study looked at the ways a state of the art digital IVET changed participants' environmental behavior and their environmental locus of control. Results showed that after being exposed to an IVE, in which they were asked to cut down trees, participants used 20% less paper and reported an increase in locus of environmental control when compared to participants who either read about the tree cutting experience or watched it in a short video (Ahn et al., 2014).

These technologies are also being used to train workers in technical skills such as oil and gas drilling. In one study, participants who were trained to drill for oil and gas using a 3D digital IVET were significantly faster and more accurate in problem solving exercises than their counterparts who learned similar skills on a 2D screen. These results suggest that these 3D experiences may be superior for training and learning purposes than other options (Gruchalla, 2004). This further suggests that the more realistic a simulation is, the more impactful it is for those involved. Plus, with data abilities doubling every 18 months the future for these technologies is boundless (Blascovich & Bailenson, 2005).

Memory and Retention

Memory is a sophisticated function that allows the brain to process ample amounts of information and decipher between the information that can be forgotten immediately, remembered for a couple minutes, and remembered for a life a time. Memory allows for organisms to learn features of their environments and plan around them. This can be as simple as planning to ensure basic survival, or it can result in more intricate learned behaviors and planning, as we see within human culture (Tetzlaff, Kolodziejewski, Markelic, & Wörgötter, 2012). Memory has many implications, and this next section will focus on memory in regard to educational learning and retention.

Without the mechanisms of memory, the brain could not retain input received. The evolution in our understanding of mathematics, science, and language are entirely reliant on our brain's ability to learn and retain information. In fact, the brain is also able to organize the information in a fashion that allows for access and application of the given memories (Pass & Ayers, 2014). This is the function of the brain that allows for conceptual change to occur, as students confront new frameworks they are able to add their new understandings to their existing mental models. Without memory, those mental models would not exist, and without the brains ability to organize and then re-organize those mental models would not be as plastic.

“The importance of the role that working memory (WM) and long-term memory (LTM) play in learning is undisputed” (Pass & Ayers, 2014, p 191). The first type of memory is called working memory (WM). Although WM is limited, it plays a crucial role in analyzing and processing the importance and application of current information that is relevant at any given moment. It is described to be what allows us to remember what we are doing in the middle of a task. It is this mechanism, combined with the “unlimited” long-term memory (LTM), that allows the human brain to be so high functioning.

Short Term Memory (STM) also play an important role, in the synthesis and processing of new information into LTM. It is the combined mechanisms of WM and LTM that define Cognitive Load Theory (CLT). CLT focuses on the brain's ability to organize and retain information and the limitations in doing so. The latest research focuses on how to "optimize learning of complex tasks by efficiently using the relation between the limited WM and unlimited LTM" (Paas and Ayers, 2015, p.192).

So, how does the brain decide what to remember and what to forget? Skulmowski and Rey (2017) showed that the way that a participant feels about themselves, their safety, distractions, etc. impacts their ability to remember. This suggests that affect plays an important role in a person's ability to make memories, and one's ability to retain what they have learned. Current educational research helps answer the question as it demonstrates the validity of hands-on, experiential learning. When students have the ability to interact and engage with a topic, it results in significantly higher degrees of mastery and retention of subject matter (Dancz, Landis, & Bilec, 2018; Prince, 2004). This suggests that memory is playing a key role in the reworking of mental models and the facilitation of lasting conceptual change.

Summary

The latest research on conceptual change, affect, learning differences, learning/teaching density, digital IVETs, and memory all informed my conceptual frameworks regarding my research question, "What are some of the lasting effects, one year after an IVET experience, both in regard to conceptual change and affect, for a small group of preservice teachers observing the molecular phenomena of density?" In the discussion of conceptual change, the *framework approach* has been identified as the leading descriptor of the phenomena, which I believe redefines and strengthens Stepan's conceptual change model used in the methods that facilitated

the 2016 CAVE experience. Furthermore, the culmination of these different branches of research suggest to me that active engagement in a positive and safe learning environment should result in an increase in mastery and retention of subject matter for all students, allowing them to build upon and rework their mental models and undergo lasting conceptual change.

Chapter 3: Research Methodology

Participant Selection

This research used a case study design that focused on four participants in order to provide an in-depth analysis of participant experience. The four participants were selected from a pool of 49 students who had participated in a previous study conducted by Dr. Buss when they were enrolled in sections of EDEL 1440: Physical Science in the Elementary School, in Fall of 2016. EDEL 1440 is a seminar course held for one hour per week, for one semester, designed to introduce content and methods for teaching physical science. This course is required for all pre-service elementary teachers studying at the University of Wyoming, during their sophomore or junior year. In one of the seminar's units, the students learned about density through an experience inside the Shell 3D Visualization Center, which is a Cave Automatic Virtual Environment (CAVE). While in the CAVE they had the chance to interact cognitively and kinesthetically with 3D digital models of water and oil molecules to build their understanding of why different liquids have different densities. Students in this course kept a journal over the course of the semester. During this specific unit, they were asked to draw the molecules of water, oil and syrup as imagined in a beaker 'pre' and 'post' the virtual experience, to expose any conceptual change that occurred as a result of their time the CAVE. The students involved in Dr. Buss's EDEL 1440 seminar provided the opportunity for me to evaluate the long-term impacts of their experience from 2016.

Only students who had demonstrated complete thoughts and drawings in their original journals from EDEL 1440, were considered as participants for this study. This gave me a solid baseline from which I could compare the drawings created one year later. Students were contacted by email in the Fall of 2017, to request their participation in the follow-up study. The

first four students who responded were chosen for this research. Students who were selected received an email of gratitude, and a request for them to share their availability to participate over the next two weeks. Based on their schedules, we set a time for the interview.

Interview Procedure

Interview questions were used to expose students' conception of density a year after their initial change in their conceptions. This was done to see how those updated understanding had or had not changed. Interviews with these participants also allowed for assessment of how the experience was remembered in regard to affect. In considering the current research question and how to best answer it, interviews stood out as the best method for data collection. As Seidman (2006) noted, "At the root of in-depth interviewing is an interest in understanding the lived experience of other people and the meaning they make of that experience" (pg. 9). This is exactly the information that was needed in order to answer the current research question concerning participant conceptual change and affect.

Each Interview took no more than one hour and was held in a local coffee shop. When a participant arrived, s/he was greeted, and offered a warm drink to compensate for time. I introduced myself and gave the participant a brief overview of my research purpose. I obtained their consent and then began with the one-on-one interview. Each participant was asked the ten questions, in the order show in Table 1. The procedures for this research followed a structured interview format at first, however after the first interview with Jane, it became clear that a semi-structured interview procedure would allow for the necessary follow up that would help expose more information about the participants' experience. (Bogden & Biklen, 2007). So, a change to semi-structured interviews occurred for the other three interviews, and probing questions were asked in order to get deeper insight on what the participants were thinking (Seidman, 2006).

Table 1

Ten Guiding Interview Questions Used with All Four Participants

Interview Questions:

1. When I ask you to reflect back on your experience in the CAVE, what are the first words or phrases that come to mind in regard to how you felt?
2. When I ask you to reflect back on your experience in the CAVE, what are the first words or phrases that come to mind in regard to what you learned?
3. So, I have asked you to think back to your experience in the CAVE, interacting with molecules of the different liquids and learning about their density (have the graduated cylinder with liquids present). If you remember, following that experience Dr. Buss had you draw the three liquids- water, oil and syrup as if you could see the molecular makeup of each. I am now going to have you draw that again. Please take a few minutes to draw these liquids in the cylinder at a molecular level to represent why they are layered in this way.
4. Explain to me what you have drawn.
5. Out of curiosity, how closely do you believe your drawing today resembles the drawing you created after your experience in the CAVE last fall?
6. I actually have your journal with me, do you mind if we take a look at it together?
7. Take a minute to look and think out loud about how you see your old drawing compared to your new drawing?
8. On a scale of 1-10, how would you rate your time in the CAVE as a learning experience? (1 highly ineffective- 10 highly effective)
9. Why did you rate your experience the way that you did?
10. Thank you so much for your time, as we have discussed, I will be reaching out in one week to follow up with you about your answers today. What questions do you have for me concerning this interview or my research?

The interview questions were developed to ensure that all the elements of the current research question were addressed. These questions were designed to guide the interview, while also remaining somewhat open (Bogdan & Biklen, 2007). The probing questions that supplemented the predetermined questions included, but were not limited to, “What more can

you tell me about the molecular structure?” and, “How did this experience compare with other physical science lessons you have experienced?”.

Throughout the interview a beaker of water, oil and syrup was present, however it was not referenced until Question 3 when it was used to prompt students to draw the beaker and its contents as if they could see the molecular make-up of the liquids. Drawing is a method that is commonly used to provide insight into a person’s thinking, understanding and experience that cannot be obtained through spoken or written word (Ozden, 2009). Another prop that was used was the journals that students had kept during EDEL 1440. Students had used them to record drawings concerning the density of the three liquids ‘pre’ and ‘post’ their CAVE experience. For the purpose of this study, only the post-CAVE drawing was considered, as I was not questioning what their change in conception was “pre” to “post”, but what they recalled one year later. The participant journal was provided after they had been asked to recreate the drawing in Q3, as a talking point for Questions 7. Lastly, during each interview I kept field notes recording anything that would not be captured on the audio recordings, such as participant facial expression and body language as anecdotal evidence. I marked down short hand for what I was noticing. The codes I used are provided in Table 2.

Table 2

Short Hand Abbreviations for Field Notes on Participant Body Language

Anger: A Confusion: C Embarrassed: Em Excited: Ex Fidgety: Fi Frown: F Furrowed Brow: FB	Head Shake: HS Lean Forward: LF Nodding: N Relaxed: R Rigid: Ri Sadness: Sa Shrug: Sh	Slouched/bored: Sl Smile Big: SB Smile: S Smirk: Sm Surprised: Su Thinking: Th
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All four interviews were audio-recorded, transcribed, and coded. One week after the participant's interview, s/he was contacted by phone at a predetermined time. The phone call, which lasted for no more than 15 minutes, served as a follow-up to the interview in order clarify answers given and to ensure that the participant had not changed their mind about any of their answers or their participation in the study in general.

Interview Analysis

Once all four interviews had been conducted, I transcribed the audio recordings and matched the transcribed interviews with my field notes on participant body language, so they could also be analyzed. With the transcriptions, I used thematic analysis for identifying the themes within my data, as it allowed me to process my data and develop themes as I found them. With the guidelines provided by thematic analysis, I used the computer coding software NVivo. The process began with a set of apriori categories; one for each research question. These were used to evaluate the connection between the interview questions and responses given. Next was to begin “open-coding” in order to identify the prominent themes and sub-themes, assign nodes to them, and then code for them throughout the interview transcripts. “Node” is a term used by NVivo to describe the themes that are being coded for.

Once all four interviews had been coded, I used the NVivo software to create a code matrix, which displayed the distribution and frequencies of the themes and sub-themes between the different participants and the different interview questions. From these figures, I was able to conduct “case-to-case comparisons”, between the four interviews, as a tool for illustrating my findings in my results. Note that the participants were assigned the pseudonyms Jane, Ellen, Conrad & Jerry in order to protect participants’ confidentiality (Braun & Clark, 2006; Creswell, 2013).

The details considered when coding included trends evident among the words, phrases, and behaviors (both reported by participants in answering interview questions and displayed by participants body language as collected in my field notes) that were demonstrated by participants. From what was observed, specific words and phrases were chosen to represent the titles for these themes and sub-themes. When faced with the choice of whether to explore a

theme or not, I considered my research question concerning conceptual change and affect as a means for determining relevancy (Bogdan & Biklen, 2007). Furthermore, I employed the method of ‘data-driven coding’, meaning that I generated the themes based on what was evident in the transcripts, and did not begin my analysis with a predetermined set that I was searching for (Gibbs, 2007). I used an outside person, one who did not share the same understanding or beliefs about education, to look over the interview transcripts and report what major themes they observed. I used this feedback to ensure that the themes that I had selected, were indeed present, and that I was not reporting something that was not evident or missing something that was.

Analysis of Participant Drawings

To analyze the drawings that participants created during their interview (Ozden, 2009), I created a set of themes in order to compare and contrast them with the drawings participants had created a year earlier. The themes were decided upon in collaboration with Dr. Buss. Drawings were analyzed based on the criteria listed in Table 3 with the help of NVivo. Drawings were considered both in regard to how similar they were to the previous year’s, and how accurate they were regarding density on a molecular scale. However, the coding process only exposed whether or not the given themes in Table 3 were present, and not whether they were accurately included. For instance, if a participant labeled oil as the densest liquid, the presence of a label would still be accounted for. This made the final step of verbally identifying and analyzing both the accuracies and misconceptions a crucial step.

The purpose of the methods used in This study were two-fold. The first was to analyze the data collected in the interviews. The second was to act as a pilot to inform methods used in another on-going study on conceptual change and the CAVE, currently being carried out by Dr. Buss.

Table 3

The Different Themes Used for Coding Participant Drawings

Shape	Size	Color	Labels/demarcations
<ul style="list-style-type: none"> - Dots - Circles - Geometry - Atomic Structure 	<ul style="list-style-type: none"> - Decrease: dense → less dense - Increase: dense → less dense - No difference 	<ul style="list-style-type: none"> - Difference between liquids - Difference within molecules - No difference 	<ul style="list-style-type: none"> - Label of liquids - Boundaries between liquids - Different densities

My Own Biases

Biases are an unavoidable element in qualitative research. However, there are means for controlling them to a degree, one of which is simply for the researcher to state what their biases are (Bogden & Bilken, 2007). My biases, as I am aware of them, that relate to this research are as follows. To begin, based on findings by researchers such as Vosniadou (2013) and the works of the National Research Council (2008) I believe that a focus on, and a better understanding of, conceptual change would greatly improve science education. I also believe that experiences are what must facilitate such changes in conception. I believe that positive affect is likely to accompany positive learning experiences. These beliefs or biases are at the root of why I wanted to study this topic in the first place. However, as the person analyzing the data in this project, it was important to ensure that I was not making meaning from the interviews that was not there, but instead approaching participant responses in an objective manner that allowed their intentions and responses to be reported. This bias was controlled by having an outside person evaluate my data as I shared in my Interview Protocols section above.

Another bias that I have is that I witnessed EDEL 1440 in action, in the Fall of 2017. Included in my observations were classroom activities and time spent in the CAVE interacting

with the virtual molecules. As a result, I had experienced the events that the students were sharing their insights on during the interviews, making it hard not to project my own experiences on the data as I collected and analyzed it. In addition, my experience is additionally troublesome, as I know that the experience of students in 2016 and 2017 varied greatly as a result of changing instructors.

Other Limitations

This study exposes a small snapshot of student responses a year after their experience in a CAVE. Although the methods of this study allow evaluation on long-term impacts, it could have been more informative had more baseline data existed especially in regard to affect. With that information, we could illustrate whether student affect changed during the lapse in time since their CAVE experience. If the four students involved in This study had been followed more closely from the beginning on both variables the insight on this experience would be even greater. The methods outlined above do provide evidence on which the conclusions from this study are drawn, but their true utility lies in how they inform future research questions and methods on this topic.

Chapter 4: Results

Introduction

At first it was a challenge to reach participants. However, once participants had committed to the study, they were eager to help and easy to work with. Each of the four participants-- Jane, Ellen, Conrad and Jerry, shared individual and unique perspectives on conceptual change and affect regarding their CAVE experience from the fall of 2016. All four of these interview transcripts are provided in Appendix A. To begin my analysis, I will tell a narrative of the interview with Conrad and describe how the different themes and sub-themes emerged from his comments. Large sections of his interview are shared, but there are also sections not included based on relevancy.

Following this narrative, the results generated by NVivo are shared and explained. I made the decision to organize my results by theme and sub-theme rather than participant because the importance and strength of the themes were diluted when they were spread throughout four different participant stories. Therefore, the sections following the narrative hold titles of emergent themes and sub-themes. An outline of these are available in the code book in Appendix B. Within each section, relevant spoken and physical (body language) responses from all four participants are analyzed. Field notes on body language were taken throughout all four interviews and are provided in Appendix C. Body language was a tool to help assess student affect, and therefore analysis of this is primarily provided in the affect sections. The final section “Drawings”, is an exception in that it is not a theme title and it includes an overview of associated of body language as well. Furthermore, the section evaluates trends observed in participant post-CAVE and interview drawings. These sets of drawings are provided in 4.

Conrad's Story

Conrad was the third participant to be interviewed. After openly sharing his positive and negative recollections of the how the CAVE made him feel, Conrad struggled to recall what he had learned in the CAVE (Appendix A). He was able to remember that “phases of matter” was a topic introduced, but only when prompted with the word density was he able to elaborate. In the following excerpt, Conrad has no recollection that oil even played a role in the learning experience, even when prompted.

Conrad- Hmm... it's kind of difficult to remember what I learned.

P- It's alright, take a minute.

Conrad- Something that stood out I think was the speed in which molecules move around I didn't quite understand before then that they were moving so quickly. Yeah, like all the time, so I would say that was probably my biggest take away, I am kind of having trouble remembering, anything else which might mean that I wasn't quite locked in or...

P- it was a long time ago.

Conrad- Yeah.

P- when I say density, does that ring any bells in regard to what you were talking about in the CAVE?

Conrad- yes. But, hard time recalling anything more. I do remember, I don't know if we looked at the phases of matter, solid liquid and gas and look at their density and their speed, I think. Maybe that was the whole thing, right? Wasn't it?

P- the Phases? That was a part of it- definitely. Talk more about that.

Conrad- um, just some rudimentary stuff, on how molecules moving, not very much in the solid phase, pretty much moving a lot in the liquid, and then all the time, very fast in the gas phase, pretty much. And then density as well, so they are a lot denser in solid- and as you move to gas they become less dense. Um, a lot more energy in gas than in liquid, liquid has more energy than solid, and that is about all I can remember from the simulator.

P- Cool, you looked at a couple different liquids in the CAVE, you looked at water, which you are speaking to as you looked into the different phases, and you also looked at oil, do you recall anything about what you learned in regard to the oil?

Conrad- mmm, no. But I do, just from other experiences, the relationship, that oil and water have, but I don't remember, specifically from the CAVE.

What makes Conrad's initial responses so interesting, is that despite his early struggles, once he had a pen and paper in his hand and was asked to draw, his memory of what he learned in the CAVE and his ability to explain it came flooding back. Prompted with a graduated cylinder with the different liquids layered inside, he created his interview drawing of the cylinder that is provided in 4. When prompted to explain the drawing he began explaining the role shape played in determining density and added details along the side of the cylinder which illustrate exactly how well he understood the material. The next excerpt shows this progression.

Conrad- So I drew our tube here, filled with syrup at the bottom, water in the middle, and oil on top. And, starting at the bottom, I drew molecules that are touching each other very close, and which represents, I don't know, how dense, syrup is, and that is why it is at the bottom. And then water, I drew molecules that are, less compact, which represents

its density. And then oil, the molecules are even further apart, which represents its even less dense properties and that is why it is on the top.

P- Great. Right on. Talk to me a little bit more about why you think that in syrup the molecules are so closely packed together and in water a little less so and oil the least so. What is going on with those molecules that make that happen?

Conrad- As you were asking the question I kind of thought it was immediately because of their shape, so that the molecules are able to be more compact, because of their shape, fitting, and like stacking bowls, you can fit a lot of them vs. plates and bowls. So, yeah, it is because of their shape.

P- Awesome, do you recall seeing the shapes in the CAVE at all, and could speak to those at all?

Conrad- Um, yeah, actually yeah, with their, uh, what you would call, chains between each one like goofy looking stuff like this, I don't know how it looked but, but then (drew molecular structure just outside the cylinder part of this drawing) it had ribbons branching out, and it was 3D so they were spinning around, it was pretty cool.

Despite Conrad's lightbulb moment while drawing, he still holds onto many misconceptions concerning density, including his mention in the first excerpt that a solid was always denser than a liquid or a gas. Another misconception that he illustrated in his drawing (4) were the hard lines representing the boundaries between the different liquids, which in reality do not exist. When Conrad had the chance to take a look at his post-CAVE drawing, things got very interesting, as he became embarrassed at how vague his notes were and how incorrect his post-CAVE drawing was. Not only did he not illustrate any difference between the molecules of the different liquids

in the cylinder, he also labeled them incorrectly (4). He tries to make sense of his drawing in the next excerpt.

P- So you are thinking of other ways other than the CAVE that you could represent this. Let's just flip the page to your drawing here, just take a minute to look at that, compare and contrast.

Conrad- I have no idea, um- is this supposed to be syrup and water- not oil?

P- I don't know.

Conrad- I honestly don't know what my thinking was, it makes no sense to me. (Reads from journal) Wouldn't the syrup molecules be smaller and heavier than the water molecules allowing them to slip through to the bottom pass the water molecules....

P- So I think that um, the question that he asked, I believe, 'What do you think the syrup molecules would look like knowing what you do about water and oil?'- you show here that oil is the denser of the two.

Conrad- but that's not true...

P- That's okay- you recognize that now though, looking at this drawing?

Conrad- Yeah- It should be syrup

P- Ah that's what you meant.

Conrad- Yeah, because I talk about syrup molecules being smaller and heavier- then water- but heaviness doesn't have much to do with it- it would be their size-

Conrad goes onto rate the CAVE experience as an "8 or 9" because of everything he was able to recall in the interview. He explained that he hadn't given the CAVE a "10" because the

technology seemed “glitchy” and that he believed another learning experience he had in EDEL 1440 was better. Overall however, it seems that Conrad was only able to access his information after he had pencil and paper to work with. Even though very similar themes emerged in the interviews of the other three participants, Conrad’s story is unique and informative. However, it is also a good representation of how the different themes and sub-themes emerged in all four interviews, which are to be discussed in the next section.

Positive Affect

Positive affect was a trend in all four interviews. There was a total of 34 comments coded as positive affect (Figure 2), making it the second most coded theme in all four interviews. Positive affect was coded when participants mentioned feelings such as enjoyment, excitement, intrigue, Positive affect was present in every answerable question in at least two of the four participant’s comments, and on only one occasion did Ellen make mention of negative feeling without an equal or greater mention positive feelings. Of the comments specifically concerning the CAVE, the number of positive affect comments were always equal or greater than the number of or safety. An example of a participant comment coded as this theme is provided in Table 4. Jane captured the overall sentiment of the larger group in regard to affect in her quote, “I really enjoyed it...”.

Although there were no subthemes of positive affect, the body language field notes (Appendix C) did inform the analysis of this theme. Things that were coded as positive affect included excitement, smiling, and relaxed demeanor. To begin, excitement was displayed by both Ellen and Conrad. Ellen displayed this when I told her that I had her journal and that she was going to get to look at it. She continued to act excited as she revisited her notes from the year prior and saw that she was on track with her most recent drawing. She was also excited to

share her reflections on specifics that she written from right after the CAVE. Conrad was excited to talk about the CAVE in Q1, but then did not become excited again until he began drawing the cylinder. It was hard to tell if he was excited about the content itself or just fact that it was coming back to him.

Question 1		Positive Affect	Negative Affect			
	Jane	3	3			
	Ellen	6	3			
	Conrad	6	1			
	Jerry	3	1			
Question 2		Positive Affect	Negative Affect	Self Doubt	CC Density	Uncertainties/ Misconceptions
	Jane	0	0	2	0	0
	Ellen	1	1	1	5	2
	Conrad	0	0	2	3	2
	Jerry	2	0	0	5	2
Question 4		Self Doubt	CC Density	Uncertainties/ Misconceptions		
	Jane	0	1	2		
	Ellen	4	4	5		
	Conrad	0	6	0		
	Jerry	0	3	1		
Question 5		Positive Affect	Self Doubt	Uncertainties/ Misconceptions		
	Jane	0	2	0		
	Ellen	1	1	1		
	Conrad	3	0	0		
	Jerry	2	1	0		
Question 7		Positive Affect	Self-Doubt	CC Density	Uncertainties/ Misconceptions	
	Jane	2	1	3	0	
	Ellen	1	0	1	1	
	Conrad	0	0	3	1	
	Jerry	1	0	4	9	
Question 8&9		Positive Affect	CC Density	Scale	Cons	Pros
	Jane	0	1	1	0	2
	Ellen	2	1	1	3	3
	Conrad	0	0	1	2	4
	Jerry	1	0	1	2	3

Figure 2. The coding matrix generated by NVivo and illustrates the frequency of the different themes and sub-themes. The Matrix broken down further by category (interview question).
^aJane’s results came from a structured interview procedure, while the other three participants took part in a semi-structured design. This resulted in Jane sharing significantly less about her experience than did the others.

negative affect comments (Figure 2). All four participants, while answering Q1, recalled their experiences in the CAVE majorly as a positive one, with eighteen mentions of positive affect, and only eight mentions of negative affect. Unlike many of the other themes, there were no sub-

All four participants also smiled during answering Q1 (How did the CAVE make you feel?). All four participants also smiled while discussing why they rated the CAVE the way that they did. Jane, Ellen and Conrad smiled throughout the entirety of the interview. In addition to smiling, Jane and Ellen remained extremely relaxed the entire interview, while Conrad only stopped being relaxed when he became very excited about explaining what he had drawn, and in Q7 when he demonstrated body language coded as negative affect.

Negative Affect

Negative affect was also a trend in all four interviews. There was a total of 9 comments coded as negative affect, making it the least coded theme (Figure 2). This code was used whenever a participant mentioned feelings of boredom, illness, discomfort, fear. The following quote from Conrad serves as an example of this theme and is also shared in Table 4.

...and a little bit, not uncomfortable because it was something new, but the guy working there was...super uptight... about all of the technology, so he kind of made us walk on egg shells as we were going through.

Eight of the nine negative affect comments occurred during Q1 (How did the CAVE make you feel?), When students were sharing comments in Q1, the only negative feelings shared regarded feeling sick, thinking that the guy who worked there was uptight, and other students' bad attitudes, meaning that reported negative affect was predominantly a result of external factors and not a result of the CAVE experience itself. The number of comments concerning negative

affect were equal to if not less than the numbers of comments concerning positive, except for Ellen, as seen in Figure 2.

Body language also informed the analysis of negative affect. Things that were categorized as negative included embarrassment, rigidity and fidgety motions (nervousness). Anger and sadness would have been coded as this theme as well, but those sorts of behaviors were not observed. As mentioned, Conrad stopped being relaxed when he was asked to look at his post-CAVE drawing, which he had done poorly. At that time Conrad became very embarrassed. Conrad was the only participant who demonstrated this behavior. Jerry was a unique case when it came to body language as he appeared uncomfortable throughout the entirety of the interview and other than some smiling at the start and end of the interview, he remained rather rigid, fidgety and kept his brow furrowed, which I assessed as negative affect.

Self-Doubt. A sub-theme that emerged within the theme of negative affect was ‘self-doubt’, and it was coded a total of 14 times (Figure 2). It was prominent within all four interviews, so I thought it was worthy to explore apart from negative affect. Self-doubt can be positive when learners are empowered to seek answers. In fact, this is an integral part of the conceptual change model as students identify and confront their misconceptions (Stepans, 2008). However, self-doubt can also be negative when the learner feels that their gaps in knowledge are dead ends (Bandura, 1997). This research identified self-doubt as a subtheme of negative affect because it was evident within these participants answers that their self-doubt was not empowering them to go and find out the right answer. Instead it was resulting in shame and embarrassment that they associated with their learning experience in the CAVE. If self-doubt and negative affect were combined, they would account for 24 comments, which was still 10 less than the total positive affect comments (Figure 2). Of interest, all four participants made

comments concerning self-doubt. These comments were evidence of the participants inability to recall specifics of what they had learned during their CAVE experience, rather than tied to the CAVE experience itself. Ellen demonstrates a code for this theme, saying:

I don't know if it's, I am either remembering my misconceptions, and this is what I thought beforehand or, this is what I drew afterwards, I can't remember which, that's what I think.

I was assessing the lasting effects of the CAVE experience in regard to affect. Therefore, these comments are very relevant to the analysis, as they expose what participants feel when they are asked to recall what they learned from the CAVE. This exposes the long-term effects of the CAVE on affect. In the preceding sections, when negative affect was discussed, the codes of the present section were not being considered, and when the codes of self-doubt are factored into the analysis the relationship between positive and negative affect changes. For example, Q1 shows a far greater number of positive affect comments than negative affect comments. However, once students began to try and explain specific content related to density, the theme of self-doubt emerged. Comments coded as self-doubt, outnumber positive affect comments on all questions following Q1 (Figure 2).

Two trends in body language that often-accompanied comments expressing self-doubt were the facial expression of a furrowed brow, and when participants were clearly 'thinking', which was recorded for any time that the participant paused and looked contemplative. Obviously, the brain is always thinking, and it is not inherently a negative thing, but this was recorded specifically when the participant took the time to ponder and work out an answer that they seemed unsure of. The interview questions asked participants to recall information from a year before, so it is not surprising that thinking was so prominent. It should

be noted that all participants took time to stop and think about the questions, and many times these long pauses or looks of hard concentration conveyed that the information the question asked about was not on the forefront of their minds and was a task to access, if they could at all. Furthermore, all four participants clearly wanted to give the correct answers, and were concerned about not knowing specific content, even when they had stated something that was correct. However, when they demonstrated that their understanding was not something they were sure about, it was coded as misconception and uncertainty, even when it was indeed correct.

Conceptual Change

Conceptual Change of Density (CC Density) was the title given to the category that accounted for any mention of a participant's accurate understanding of molecular density. There were 40 comments coded as CC Density, making it the most coded theme (Figure 2). As a result of the questions asked during this interview, participants shared a great deal about their understanding of density, exemplifying the understanding that they walked away with, as Ellen demonstrates in the following comment, which is also provided in Table 4.

I think the biggest thing was that it wasn't the molecules themselves that were denser, it was just the way that they fit together with each other, so water fits together more tightly and is therefore denser.

All four participants shared understandings that were coded as CC Density. All four participants also seemed confident in the role that the space between molecules played in determining density, and that liquids stack from the densest on the bottom and the least dense on top. Participants often repeated this content during different parts of the interview, in which case the comments were coded multiple-times. For example, if during Q2 a participant shared that it

was the space between the molecules that determined density, and then restated that same understanding in question 7 (Q7), both comments were coded as CC Density.

Table 4

Provides Examples of Comments Made by Participants for Each Theme

- **Positive Affect**
 - “I really enjoyed it. It was enjoyable” (Jane).
- **Negative Affect**
 - “...and a little bit, not uncomfortable because it was something new, but the guy working there was um, super uptight, so just about all of the technology, so he kind of made us walk on egg shells as we were going through” (Conrad).
- **Self-Doubt-**
 - “I don’t know if it’s, I am either remembering my misconceptions, and this is what I thought beforehand or, this is what I drew afterwards, I can’t remember which, that’s what I think” (Ellen).
- **CC Density**
 - “I think the biggest thing was that it wasn’t the molecules themselves that were denser, it was just the way that they fit together with each other, so water fits together more tightly and is therefore denser...” (Ellen).
- **Misconceptions/Uncertainties**
 - “I’m sure that if the molecule is larger, there will be more space between it, and if it is a smaller molecule it allows them to get closer together, and avoid that space, and then another thing I said it depended on was like the temperature of the molecules, like at high temp, when it is boiling it moves to the top, so maybe the molecules shrink, or expand, and when it gets cold, they shrink and shrivel, and allow them to fall lower” (Jerry).
- **Scale**
 - Jane- “...probably like an 8. Or a 9.”
 - Ellen- “...I think 9.”
 - Conrad- “The actual experience probably 8 or 9...”
 - Jerry- “It probably would have been, 7... but now I would probably say about a 6.”
- **Pros**
 - “I don’t know, just the excitement, it was something new, like the not really understanding what a 3D CAVE is like seeing it work, in its full capacity was really cool... I was just happy and excited to be learning” (Jerry).
- **Cons**
 - “I don’t remember specifically what it was, if the software was acting up that day- but it was rather glitchy- and hard on your eyes, just kinda glitchy, hurt your head to look at it” (Conrad).

Misconceptions and Uncertainties. ‘misconceptions and uncertainties were coded as a CC Density sub-theme. There was a total of 26 comments in this subtheme (Figure 2). As participants shared their conceptual change from the CAVE, many were either flawed, or shared with little to no certainty. Jerry called the space between the molecules “air”, which resulted in the following exchange:

P- ...is the same kind of air that we are breathing in between these molecules?...

Jerry- I would say it is probably the same... This understanding, and the others coded, still represent conceptual change within the participant’s mental model of density. Differentiating between what was and was not understood is important to determine what was effectively communicated and what was not. The purpose of the CAVE simulation was not to simply change conception, but to update the frameworks that students possessed concerning density with the best available explanation for the phenomenon.

All four participants shared comments that were coded as misconceptions and uncertainties, and example of these comments is provided in Figure 3. When answering Q2 (What did you learn from the CAVE?) Ellen, Conrad and Jerry all shared more CC Density comments than they did misconceptions and uncertainties comments. The exception was Conrad, who began with an equal number of comments concerning CC Density and misconception and uncertainties and after drawing shared zero comments that were coded as misconception and uncertainty. On the other hand, Ellen and Jerry became less and less confident in their overall understanding as the interviews went on. Jane was unable to come up with an answer for Q2, but like Conrad, was able to recall some content after she had the chance to draw the beaker and its contents (4).

The comments coded as misconceptions and uncertainties varied between participants. For example, both Conrad & Jerry stated that ice was denser than water. Ellen tried to explain what resulted in differing levels of space between molecules. Jane was on the verge of being uncertain about everything she shared, even the correct information, and it was difficult to determine whether to code her answer as CC density or as uncertainty. All four participants shared something with certainty and then retract their statement quickly, which became the most common kind of comment coded as this theme.

Scale

All four participants shared their opinions on how their CAVE experience should be rated on a Likert scale 1-10, and their responses are shared in Table 4. Jane, who was able to share the least amount about what she learned and seemed the least certain throughout the entire interview, rated the experience the highest at a 9, while Jerry, who expressed zero comments of self-doubt in his understanding of density, gave the lowest rating of a “5 or 6” as a result of his perceived lack of retention. The other two participants both gave the rating of “8 or 9”. These ratings show that overall participants feel positive about the CAVE experience. This was based on the ratings of three of the four participants. With that said, the only relatively low score reveals that Jerry believed he *should* be able to recall more than he did, and it also reveals his notion that his one CAVE experience *should* have taught him more.

Pros & Cons. After participants shared their scores, they shared why they rated the experience as they did. This resulted in the two sub-themes, ‘pros’ and ‘cons’ of the CAVE experience. As seen in Figure 2, a total of 12 comments were coded as ‘pros’ and a total of 7 comments were coded as “cons”. In this section they will be discussed together, to compare the variety in the comments made.

Jane shared several pros about the experience but could not come up with any cons, even after prompted. The other three participants shared a relatively even list of what they appreciated and what they did not. Ellen and Conrad both stated that after the interview they felt they had recalled a lot about the experience, and that was a reason they rated it so high. Jane and Jerry thought that being able to interact with the molecules was a pro, and Jerry shared the following.

I'm a very visual learner, so being able to see the different liquids...since they were different colors you could clearly see when one stopped and when one began....you could even see if there was a mixture point and watching I remember him putting ...water in and then syrup in and watching as the syrup went through the water and having the water rise to the top. I thought that was ...a good way to like... understand ...the density of liquids more or less.

Additionally, all four participants stated that the novelty of the technology and the excitement about being in the room were pros as well.

Comments coded as cons by the participants were varied, but trends were evident. While Ellen and Conrad shared that their ability to recall content informed their high ratings of their experience, Ellen, Conrad, and Jerry stated that they wished they had been able to recall more, and that their inability to do so was a factor in their rating not being higher. Ellen also noted the insight that her misconceptions and uncertainties in the interview were the same misconceptions and uncertainties she had coming out of the experience, and the lack of follow up or clarification post-CAVE was the biggest issue with the CAVE experience itself.

Conrad realized that he thought a moon phases lesson from EDEL 1440 was taught better, and that was why he didn't give the CAVE a higher score. Ellen and Conrad both shared that the simplification of molecules and density in order to make them compatible with CAVE

capabilities actually lead to the misconceptions that they walked away with. Yet, Jerry claimed that he saw downside to the simplifications.

Analysis of Participant Drawings

During the interviews all four participants were asked to draw a beaker with syrup, water and oil, and then they compared the most recent drawing to the post-CAVE drawing they had made a year before. These four sets of drawings are shared in Figure 3. From these drawings two major findings emerged. The first, is that all four interview drawings communicated a strong understanding of molecular density, and in the case of Jerry and Conrad, an even more accurate understanding was communicated than in their post-CAVE drawings. Jane was alone in having a more complete drawing post-CAVE, but as mentioned, the interview method changed from structured to semi-structured after her interview, due to the limited insight she provided. This means that although her drawings are included in Figure 3, they could not be directly compared to the other three drawings.

The second finding from the drawings in Figure 3 is that even though all four participants produced accurate drawings during the interview, none of the drawings appeared to be an attempt to simply recreate the drawing they had done the year before. Instead, all drawings appeared to be an attempt at simply creating a drawing that communicated their conceptual understanding of molecular density. To note, all four participants reported that they had received no follow up course work or formal exposure to the topics of molecular density after their experience in the CAVE in EDEL 1440.

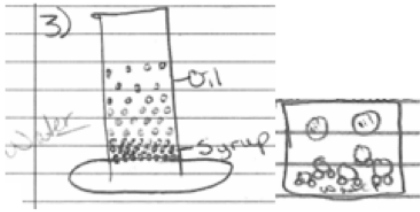

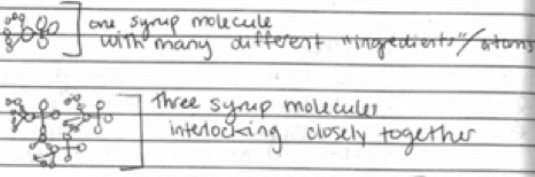
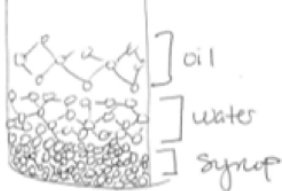
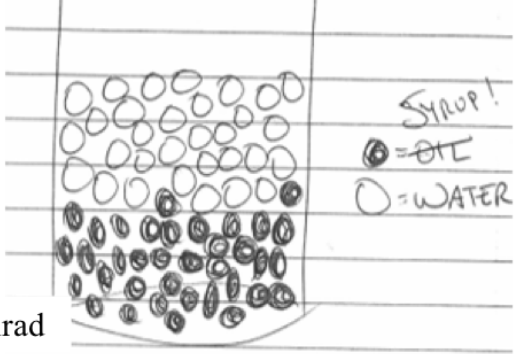
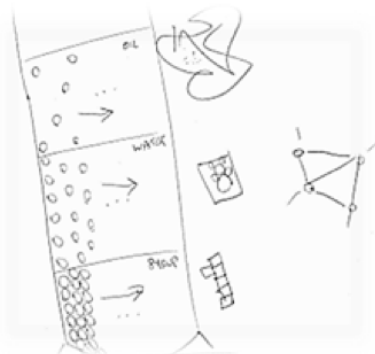
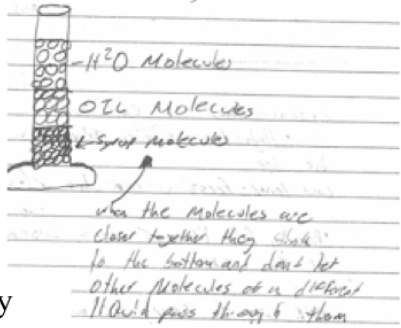
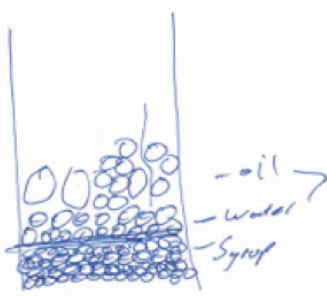
Post CAVE Drawing	Interview Drawing
<p data-bbox="269 464 331 495">Jane</p> 	
<p data-bbox="269 701 342 732">Ellen</p> 	
<p data-bbox="269 1073 370 1104">Conrad</p> 	
<p data-bbox="269 1430 337 1461">Jerry</p> 	

Figure 3. The post-CAVE and interview drawings of all four participants.

^a Conrad made the correction to his liquid labels on his post-CAVE drawing during the interview, when he saw that he had made the mistake.

Chapter Five: Conclusion

This chapter explains results and draws conclusions on their implications. It also addresses critiques of the research methods and makes recommendations for future study. This section will discuss the findings in terms of the research question: “What are some of the lasting effects, one year after an IVET experience, both in regard to conceptual change and affect, for a small group of preservice teachers observing the molecular phenomena of density?” The discussion will begin with participant affect, and finish with conceptual change.

Discussion

Affect. The four participants interviewed provide only a small glimpse into what the larger group of students felt during their experience in the CAVE. The results showed that when considering negative versus positive affect (without considering self-doubt), participant responses trended in the positive direction. When students were asked Question 1 (How did the CAVE make you feel?), 18 of the 26 comments were positive. Participants talked about the CAVE using words such as “cool” and “exciting”, and comments containing those words were the most frequent of those coded as positive affect. Two of the four students had been to the CAVE before, but still found the experience novel. Throughout the four interviews, positive affect was demonstrated through body language, as participants became excited about their experience and the content matter they were sharing. Participants also smiled when recalling their experiences and what they learned, and three of the four participants remained relaxed throughout the majority of their interview.

Negative affect demonstrated by participants appeared to manifest from feelings of self-doubt and uncertainty about what they knew regarding molecular density. These feelings only came up during questions when students were asked to recall the specifics of the lesson they had

on density in the CAVE. However, it seemed that after participants shared critiques of the experience they would then immediately make positive comments. This could have resulted from students trying to give the answer they thought I was looking for, as they almost seemed guilty about saying anything that was not positive. For instance, Ellen said,

I think people just didn't want to leave the classroom... I don't know... just sit there and text if they wanted to... I think I was disengaged for a while because I was like the third group to go. So, I just sat there for a while... I'm not sure this is helpful...I guess I would say I was excited, I was super excited to experience it and see it...

However, there is no way to know that for sure since I did not directly ask them about feelings of guilt.

Body language expressed throughout the interviews generally came off as relaxed and positive, and only two students portrayed behaviors that I characterized as negative. Conrad became embarrassed about his post-CAVE drawing and Jerry remained uncomfortable throughout most of his interview. There is no way to know what factors were impacting the Jerry's demeanor. In other words, was it the interview? Or was it other things going on in his life? Body language was hard to draw conclusions from, as it is a very complicated topic to analyze (Patel, 2014). Issues with the method will be discussed more in the next section.

In summary, the long-term effects of the CAVE experience on these four participants' affect appeared to be both positive and negative. Participant affect was negatively impacted by feelings of self-doubt and uncertainty about the content they learned in the CAVE. Although the experience itself seemed positive for the most part, the fact that these participants' understanding of density was only partly understood and remembered resulted in long term negative affect as they tried to recall the content. Indeed, without the interview process these students may not have ever realized the gaps in their knowledge, and their feelings would be limited to what they shared

in response to Question 1, which were primarily positive recollections. These findings suggest that the CAVE experience would benefit from some changes in implementation that would help cultivate a more positive learning environment for students, because with positive affect cultivates better learners (Immordino-Yang, 2011). Such changes could include: creating positive interactions with students in the CAVE environment; creating stations so students are not just sitting around waiting their turn; and working with students on the process of conceptual change so they realize that the one CAVE experience is not meant to stand alone. Furthermore, I recommend a shift to the facilitation of an experience where the goal is to create self-sustaining learners, and not just to impart specific content.

Conceptual Change. The results from this study were able to inform and answer the research question concerning the long-term effects of the CAVE experience on student conceptual change. Recall that pre-service teachers often have a limited understanding of density (Stepans, 2003; Kiray, Aktan, Kaynar, Kilinc, & Gorkemli, 2015) and that conceptual change no longer represents the process of replacing wrong information with right. Instead, it is a phenomenon of building upon pre-existing understandings as new information is introduced in an ongoing process (Vosniadou, 2013). This supports the assertion that understandings (correct or flawed) mentioned by participants were informed or solidified by their CAVE experience and can therefore be counted as evidence of participant conceptual change.

The slow integration of information is not what happened, as students experienced the CAVE lesson and observed density on a molecular level for only about five minutes. The assumption that one experience in a virtual reality will completely rework a student's understanding of density is not supported by the literature and is not what was observed in this study. Instead, students observed and experienced the new information and then worked to fit it

into the frameworks they already had. This is not to say changes in student understanding did not occur. One example of a shift in thinking that was displayed by all four participants was the idea that density is defined by the space between molecules. However, each of them had a different explanation for why that space existed. As the framework theory of conceptual change suggests, this resulted from participants using their life experiences and what they knew content-wise to come up with explanations to fill their gaps (Vosniadou, 2013). For example, Ellen ventured the guess that it was the bonding between or within the molecules that resulted in the space, while Jerry stated that it was size of the molecule alone that determined it. Neither of these participants seemed sure about this information, which resulted in feelings of self-doubt.

All four participants seemed to feel pressure to give correct answers and frustration with themselves when they did not know the answer to the question I was asking. Ellen shared that she believed she had the same gaps in understanding in our interview as she had directly after her experience. Based on the participant drawings, this may be true for all four participants.

Drawings were useful in exposing participant understanding of density as they provided insight into thinking, understanding and experiences that could not be obtained through spoken or written word (Ozden, 2009). Interestingly, a relatively strong grasp of molecular density was communicated through the participant's interview drawings. This was even true for participants who, based on their post-CAVE drawing alone, appeared to have a weak grasp on the content.

As mentioned, all four participants reported that they had not had any follow-up course work or formal exposure to the topic of molecular density, which would suggest that the drawings created in the interview were likely the result of what they had learned the year prior. The gaps in understanding do not seem to be a result of lapse in time, but instead the result of one isolated learning experience.

Recommendations for future study

In addition to seeking answers to the research question, this study also sought to act as a pilot to assess the methods used to gather the data. The methods of this study were influenced by Dr. Buss's previous work assessing the impacts of the CAVE as a learning tool. However, the methods used in this study stand to improve in four major ways:

- 1) **Gather more in-depth baseline data on student's conceptual frameworks about density prior to any intervention.** This would allow for more certainty in research claims concerning what changes occurred regarding student conceptual frameworks. Interviews or an in-depth questionnaire could garner this information.
- 2) **Gather data on student affect during and directly after the CAVE experience.** Speaking to students a year after their experience provided only one snapshot of how the CAVE impacted their affect. Being able to observe students throughout the experience would allow for a more holistic grasp on the CAVE's impact, and how time shaped their memory of these feelings.
- 3) **Revamp the study's evaluation of body language.** This was the weakest part of this study's methods. To begin, the necessary background research into the study of body language occurred after the interviews had taken place and the field notes gathered. Considering that there are over 700,000 expressions that the body can perform (Patel, 2014), my approach in creating a short list of 20 possible things that I would make note of really limited the potential for analysis. Furthermore, things like "thinking" and "excitement" are what the body may be communicating but not what the body is doing. In the future, video analysis could make it possible to capture more of the participants body language and to connect those gestures and expressions with

specific comments and thoughts that they coincided with. However, due to the complex nature of body language (Patel, 2014), it seems appropriate to employ the expertise of a behavioral specialist for analysis of this data if body language is considered in future study.

- 4) **Conduct multiple interviews with each participant.** Based on the Hawthorne Effect (which suggests that participants are likely to act and respond differently when observed, especially by a stranger) it can be assumed none of the participants in this study were able to act natural or think clearly based on the fact that I was present, and they were being recorded (McCambridge & Elbourne, 2014). According to Siedman (2006) three interviews is the golden number, as the researcher can build rapport in interview one, ask hard-hitting questions in interview two, and clarify and follow-up in interview three. It is not always possible to control for the Hawthorne Effect, as it is still misunderstood in regard to the effect itself and how to mitigate it (McCambridge & Elbourne, 2014). However, increasing the number of interviews could help control for its impact on participant behavior and ultimately the soundness of future results.

Three follow up questions also emerged from this research: a) Does a focus on conceptual change in the framing of a learning experience alter student perception of their gaps in knowledge one year later in regard to affect? b) What misconceptions are introduced into student frameworks as a result of the CAVE experience? c) Is the CAVE more effective at facilitating conceptual change of molecular density than traditional classroom lessons in regard to the accuracy of content and long-term retention? In answering these questions, a more robust understanding of the CAVE's impacts on student conceptual change and affect will be acquired.

Conclusion

What the four participants of this study learned during their CAVE experience did in fact withstand time. This finding is supported by the literature, which provides that experiential learning is often superior. In fact, when hands-on learning is engaged, an increase in mastery and retentions of new concepts ensue (Prince, 2004). These participants did harbor negative affect in regard to the CAVE, but these feelings were in regard to external factors and not to the CAVE experience itself. Furthermore, evidence of self-doubt emerged from participants' feeling that they should have known more about density than they did. These factors could be managed in the future. For example, the updated frameworks that students developed and made a part of their understanding, included *both* the accurate understandings (more space between molecules = less dense) and the gaps in understanding (space between molecules is a result of ____). These incomplete frameworks concerning molecular density were expected, as conceptual change is ongoing process of building frameworks, and it does not happen in one isolated experience (Vosniadou, 2013). If students are made aware of this process, and empowered to be an active participant in it, they may feel less negatively about their gaps in understanding going forward.

The gaps in knowledge observed in this study are not a testament to the CAVE as a learning tool, but instead that one isolated learning experience is not enough to update and rework every student misconception on a topic (Vosniadou, 2013). Due to participants' apparent belief that the one experience should have solidified their understanding, and then their realizations in the interview that it did not, the four participants demonstrated negative affect in the form of self-doubt. With that said, the results of this research showed long-term impacts of the CAVE experience for these four participants in regard to conceptual change and positive affect.

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Appendix A

Transcripts

Transcripts are available from the author by request.

Appendix B

Code Book

Analysis of Categories, Emergent Themes & Sub-Themes	
<ul style="list-style-type: none"> ▪ Question 1 <ul style="list-style-type: none"> ↳ Positive Affect ↳ Negative Affect ▪ Question 2 <ul style="list-style-type: none"> ↳ CC Density <ul style="list-style-type: none"> ↳ Uncertainties ↳ Positive Affect ↳ Negative Affect <ul style="list-style-type: none"> ↳ Self-Doubt ▪ Question 4 <ul style="list-style-type: none"> ↳ CC Density <ul style="list-style-type: none"> ↳ Misconceptions/Uncertainties ↳ Positive Affect ↳ Negative Affect <ul style="list-style-type: none"> ↳ Self-Doubt ▪ Question 5 <ul style="list-style-type: none"> ↳ CC Density <ul style="list-style-type: none"> ↳ Uncertainties/Misconceptions ↳ Positive Affect ↳ Negative Affect <ul style="list-style-type: none"> ↳ Self-Doubt ▪ Question 7 <ul style="list-style-type: none"> ↳ CC Density <ul style="list-style-type: none"> ↳ Uncertainties/ Misconceptions ↳ Positive Affect ↳ Negative Affect <ul style="list-style-type: none"> ↳ Self-Doubt 	<ul style="list-style-type: none"> ▪ Question 8&9 <ul style="list-style-type: none"> ↳ CC Density <ul style="list-style-type: none"> ↳ Uncertainties/ Misconceptions ↳ Positive Affect ↳ Negative Affect <ul style="list-style-type: none"> ↳ Self-Doubt ↳ Scale ↳ Pros- ↳ Cons- ▪ Drawing <ul style="list-style-type: none"> ↳ 1 Year <ul style="list-style-type: none"> ↳ Size <ul style="list-style-type: none"> ↳ Molecular Structure ↳ Color ↳ Labels and Boundaries ↳ Shape ↳ Post-CAVE <ul style="list-style-type: none"> ↳ Size <ul style="list-style-type: none"> ↳ Molecular Structure ↳ Color ↳ Labels and Boundaries ↳ Shape ▪ Other Experiences <ul style="list-style-type: none"> ↳ Positive Affect ↳ Negative Affect
<p>Demonstrates the process of identifying emergent codes during data analysis. Each question was analyzed separately and based on what participants shared the categories and themes above were identified.</p>	

Code Book

Positive Affect: Any reference to positive feelings by the participant in regard to the CAVE experience.

Negative Affect: Any reference to negative feelings made by the participant in regard to their Cave Experience.

CC Density: Any attempt by participant to explain the concept of density with a level of certainty.

Uncertainties: Any information that the participant shares but seems confused by or is still questioning.

Self-Doubt: Any indication that a student is feeling insecure in what they are sharing. Specifically phrases like “I really don’t know”, “I am not sure”, or “I can’t remember”.

Scale: Question 8 asks participants to rate their experience on a Likert scale of 1-10; any reference to this scale will be coded as under this theme.

Pros: Any positive elements shared by participant about the CAVE as explanation for why they scored the CAVE experience the way that they did on the Likert scale.

Cons: Any negative elements shared by participant about the CAVE as explanation for why they scored the CAVE experience the way that they did on the Likert scale.

Drawing: Each participants had two drawings for analysis; one from directly after the CAVE experience and one from their interview one year later.

Post-Cave: The drawing from directly after the CAVE experience.

One Year: The drawing from one year after the CAVE experience.

Spacing: Any indication in the participant drawing that there is space between the molecules resulting in different densities.

Color: The presence or absence of color in the drawing to help distinguish between the different liquids and their densities

Size: The presence or absence of different size molecules in the drawing to help explain the different liquids and their densities

Molecular Structure: Any indication of molecular structure in participant drawing used to explain density.

Labels or Boundaries: Any indication of labels or boundaries between different liquids.

Question 1: When I ask you to reflect back on your experience in the CAVE, what are the first words or phrases that come to mind in regard to how you felt?

Question 2: When I ask you to reflect back on your experience in the CAVE, what are the first words or phrases that come to mind in regard to what you learned?

Question 4: Explain to me what you have drawn?

Question 5: Out of curiosity, how closely do you believe your drawing today resembles the drawing you created after your experience in the CAVE last fall?

Question 7: Take a minute to look and think out loud about how you see your old drawing compared to your new drawing?

Question 8&9: On a scale of 1-10, how would you rate your time in the CAVE as a learning experience? (1 highly ineffective- 10 highly effective) Why did you rate your experience the way that you did?

Appendix C

Body Language Field Notes

	Q1	Q2	Q3 (Drawing)	Q4	Q5	Q7	Q8&9
Jane	LF, N, R, S	FB, R, S, Th	FB, R, S, Th	R, S	N, SB, R	N, R, Su, S	FB, N, R, S, SB, Th
Ellen	FB, N, R, S, Th	FB, Fi, S, SB, Sm, R, Th	Fb, Ri, Sm, Th	C, Ex, FB, Fi, N, S, SB, Th	S, R	C, FB, R, S, SB, Th	S, SB, R, Th
Conrad	Ex, N, R, SB	FB, Fi, Em, R, Th	FB, N, R, Th	FB, Ex, R S, Th	Ex, FB, N, SB, Th	C, FB, Em, Fi, HS, SB, Th	FB, Ex, N, S, SB, R, Th,
Jerry	FB, Fi, S, Th,	FB, Fi, Th	FB, Fi, N, S, Th	FB, Fi, Th	FB, Fi, Th	C, FB, Fi, Th	FB, Fi, R, S, Th
KEY:							
Anger: A Confusion: C Embarrassed: Em Excited: Ex Fidgety: Fi Frown: F Furrowed Brow: FB		Head Shake: HS Lean Forward: LF Nodding: N Relaxed: R Rigid: Ri Sadness: Sa Shrug: Sh		Slouched/bored: Sl Smile Big: SB Smile: S Smirk: Sm Surprised: Su Thinking: Th			

Field notes on body language from the four interviews, organized by participant and by category (interview question).