Bypassing, Skipping, and Pivoting: A Behavioral Microanalysis during an Information-Based Task in Spatially-Diverse Virtual Environments

by

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Abstract

Educators are looking at technology voluntarily used by students outside the classroom as a way to better engage students inside the classroom. This study examined post-secondary students' behavior during an information-based task in spatially-diverse virtual environments. Cluster analysis identified four student profiles based on video game and social media experience, along with perceived and demonstrated spatial skills. Results revealed proportionately high student membership in the profile characterized by low video game and social media experience. Behavioral microanalysis was conducted on a video-recorded participant subsample. The microanalysis identified elements that contributed to positive or negative economizing as participants learned to navigate the virtual environment during task completion. Case studies investigated participants' behavior within the contexts of student profile and spatial condition. Results raised questions about the role of reduced navigational cognitive workload in creating barriers to information-task engagement, along with the potential role for higher embedded cognitive workload to generate engagement.

Keywords: Virtual environment, video games, social media, spatial skills, cluster analysis, student profile, behavioral microanalysis, case study

Preface

The following preface is mandatory because ethics approval was received for the study associated with this thesis. This thesis is an original work by Heather May Gautreau. No part of this work has been previously published. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics board (2) on December 13, 2016, under the project name, "The Effects of Spatial and Social Elements on Learning in Virtual Environments", Study ID: Pro00069630.

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Introduction

Educational institutions who once set the pace for the introduction of new knowledge have now come face-to-face with the unprecedented experience of needing to keep up with an entire society that is information-based and constantly changing (Fernandez-Aviles, Perez-Zabaleta, Martinez-Merino, 2014). Chang, Gütl, Kopeinik, and Williams (2009) warned that "a paradigm shift is occurring" (p. 7), while Frand (in Broussard, 2009) pointed out that students' ever-rising usage of computers and technology is "hardwired into their psyche" (p. 904). These comments are indicative of concern that the students of today are easily bored by the teaching approaches of yesterday (Oblinger & Hagner, 2006, in Akcayir, Dundar, & Akcayir, 2016). In a world where students are often early adopters and prolific users of new technology (Grosch, Berger, Gidion, & Romeo, 2014, Rozin, 2010, Urso & Rodrigues Fisher, 2015), there is increasing awareness that the field of education must keep pace with current technological trends and that "contemporary and sustainable learning environments must be created to cater [to the current] generation of learners" (Chang, et al., 2009, p. 6), lest the delivery of education be outstripped by the very students that it hopes to teach (Bauer, 2007, Chang, et al., 2009, Holmes & Gee, 2016, Kopcha, Reiber, & Walker, 2016, Omar, Kalulu, & Alijani, 2011, Prensky, 2006, Smith, Samors, & Mayadas, 2008).

In recognition of this concern, the *2010 National Educational Technology Plan* (U.S. Department of Education, 2010, in Kopcha, Reiber, & Walker, 2016) made a bold request for post-secondary institutions to increase their application of state-of-the-art technology in the pursuit of "engaging and empowering experiences that prepare [learners] [to be] participants in our globally networked society" (p. 945). Hampel (2014) agreed with the urgency of the Department of Education's assessment, making the point that information and communications technology (ICT) was “essential for everybody to succeed in almost all areas” (p. 35) and that “Today the question is not whether ICT should be used, but how” (p. 36). Hanewald (2013) agreed, unequivocally declaring that “skills and experience in online environments are needed for employment and life-long learning” (p. 240). Omar, et al. (2011) laid down their own definitive word on the matter, explicitly stating, “It is clear that universities need to adapt to the impact of technology on learning” (p. 38).

One way to counter the risk of obsolescence in education is to use current technology for the delivery of learning material. However, one of the challenges of this approach is that students, despite the understanding of their high level of technology usage overall, seem far less likely to employ their technological skills toward the type of learning that educational institutions wish to deliver (Akcayir, Dundar, & Akcayir, 2016, Lei, 2009, Ng, 2012, Thompson, 2013). As such, it becomes important to tap into the momentum of the media usage that is already occurring on students’ own time (Bauer, 2007, Broussard, 2009, Dobre, 2015, Hanewald, 2013, Prensky, 2006). Virtual environments (VEs) are one form of technology in which students are investing substantial amounts of their own time and energy: the popularity of virtual environments is substantial and expected to continue rising (Cherbakov, Brunner, Lu, & Smart, 2009, in Hanewald, 2013, Wu, Mattingly, & Kraemer, 2015). When Chang, et al. (2009) conducted a study on the use of virtual environments as an approach to collaborative education that targeted “the new generations of learners” (p. 7), the authors were already anticipating that within two years of their study, 80% of individuals who consistently used the internet would have created their own *presence* (e.g. avatar) within a virtual environment.

Due to virtual environments’ seemingly limitless ability for customization (Maratou, Chatzidaki, & Xenos, 2016), the New Media Consortium and EDUCAUSE Learning Initiative considered virtual environments to be ideal for a boundless range of purposes that could occur in almost any type of setting (2007, in Hew & Cheung, 2010). As such, virtual environments can provide new opportunities for the delivery of educational experiences (Yasar & Adiguzel, 2010) that can help to alleviate the perceived indifference of learners who are disengaging from traditional approaches to education (Kopcha, et al., 2016). Indeed, students, themselves, have identified the use of virtual environments for education as potentially advantageous to their learning (Hew & Cheung, 2010). Studies have found that learning tasks within a virtual environment can be as effective (or even more so) than learning the same tasks in a real-world environment (Bombari, Schmid, Canadas, & Bachmann, 2015, Waller, Hunt, & Knapp, 1998, Waller, Knapp, & Hunt, 2001, Whitten, Enicks, Wallace, & Morgan, 2013, in Ludlow, 2015). These findings suggest that virtual environments are a viable option for content delivery and learning acquisition. Indeed, well-respected institutions such as the Massachusetts Institute of Technology (MIT), Harvard, and Princeton, are already utilizing virtual environments as a delivery platform for online learning opportunities (Hanewald, 2013).

It is for these types of reasons that Hanewald (2013) stipulates the importance of capturing an understanding of best practice with regard to the use of virtual environments as platforms for learning. Other researchers clearly agree, for a number of studies have focused on deepening understanding in this field. For example, several studies have measured the demonstrated behavior of participants during a task in a virtual environment. Latu, Mast, Lammers, and Bombari (2013) looked at the behavior of individuals who were exposed to positive role models during a virtual public speaking activity. The authors identified a behavior (length of time spent speaking) associated with the study's target construct of empowerment; that coupling allowed the authors to quantify empowerment by noting the speaking time of participants in the study (Latu, et al., 2013). The authors then video-recorded participants during their delivery of a speech in front of an audience of twelve *agent-avatars* (see *Literature Review* section, *Virtual environment* subsection); for three of the four conditions in the study, a portrait was hung on the back wall of the virtual room behind the audience. The authors noted each participant's speaking time and compared the number of seconds that each participant spoke to their self-rated performance, and to an external evaluation of the quality of their speech delivery (Latu, et al., 2013). The results of the study showed that regardless of whose portrait was on the back wall (including the no-portrait condition), male participants spoke for approximately the same amount of time. However, female participants spoke for less time than males if the portrait was absent or featured an influential male leader (Bill Clinton), but females spoke equally as long as males when the portrait featured an influential female leader (Hilary Clinton, Angela Markel) and their self-reports rated longer speeches as being of higher quality (Latu, et al., 2013).

Other studies have focused on analyzing verbal behavior (conversation) within a virtual environment. For example, Heller and Procter (2014, in Wu, et al., 2015) analyzed short, undirected conversations between participants and a computer – named "Freudbot" – that took place either using a text-based form of communication, or within a virtual environment. The authors quantified participants' use of personal pronouns and elements of speech related to cognition, biology, and past/present terminology. The results of the analysis revealed that participants who engaged in conversation in the virtual environment had higher usage rates of the target speech elements (Heller & Procter, 2014, in Wu, et al., 2015).

Kramer, Oh, and Fussell (2006, in Wu, et al., 2015) found significant differences between participant conversations held via four diverse mediums that were all delivered via computer mediation. The authors counted the frequency of participants' pronoun use and found that participants with a high self-reported sense of feeling 'present' used "we" pronouns more often, while those feeling a lower sense of presence used "you" pronouns more often (Kramer, et al., 2006, in Wu, et al., 2015).

Wu, et al., (2015) studied conversations between participants and a confederate-controlled *human-avatar* (see *Literature Review* section, *Virtual Environment* subsection) in two virtual environment conditions featuring very different environmental stimuli. Using a within-subjects design and focusing on text-based communication, the authors analyzed the nature of the written communication and found marked changes in speech patterns between the conversations held by participants when they were in a low-stimuli virtual environment designed to appear as a lab setting, and the conversations that they held within a high-stimuli virtual environment designed to appear as an amusement park setting (Wu, et al., 2015).

Taking a different approach to investigating the impact of 'physical' characteristics on participant behavior, Lam and Riedl (2011) looked at the relationship between the appearance of an avatar, and the behavior of the participant who was controlling that avatar during a role-playing game. The authors found that participants would modify their avatar's behavior (and therefore, their own) during the game in order to 'match' an avatar's behavior with its appearance (Lam & Riedl, 2011).

There have also been a number of studies looking at participant behavior related to general technology use in education. For example, Smith, et al. (2008) focused on the prevalence of online course registration, and found that it was occurring at ten times the current rate of institutional post-secondary registration. Patterns of student behavior with regard to online navigation of search engines, websites, and/or web-based platforms have also been investigated, with results that reveal a trend toward a lower usage of technology for learning purposes (Coklar, Yaman, & Yurdakul, 2017, Marques & Belo, 2011, Toprakci, 2007), despite the understanding of relatively high usage for personal reasons.

In summary, a variety of disciplines have studied participant behavior via the use of technology, or in relation to the use of technology. However, few studies have focused on the navigational behavior of learners while in a virtual environment, and even fewer on using behavioral microanalysis to analyze the frequency of specific avatar navigation and/or camera manipulation behaviors that may contribute to, or detract from, information retention. In addition, much of the study that has been undertaken on using virtual environments for educational purposes has focused primarily on identifying and evaluating direct evidence of information recall or skill demonstration, or on developing an understanding of the experience of learning in a virtual environment as reported by participants.

Although technology has advanced at an unheralded rate of development over the two decades since Cotter, Burgio, Hsu, and Hardin, (1998) engaged in the study of video-recorded and computer-assisted behavioral microanalysis, there remains a dearth of behavioral microanalysis conducted during completion of an information-based task within a virtual environment. This lack of study raises a host of unanswered questions. What do students *do* while they are “in there”? What don’t they do? Is what they *do* do effective for accomplishing the purpose of an information-based learning task? Does the physical representation of a virtual environment affect what students do? Who does what? Who doesn’t do what? In other words, how do different types of students behave differently? And finally, possibly the most important question of all: What are the implications of the answers to the above questions? It is in recognition of the import of answering the above questions that the current study was conceived.

The objectives of this study are twofold:

1. Investigate and define the presence of distinctive homogenous groupings – *profiles* – within a sample of students with regard to their computer experience and spatial abilities
2. Conduct an in-depth observation and investigation of individual student behavior representing different student profiles and occurring within diverse virtual environment spatial conditions

The above objectives gave rise to two primary research questions which will guide the course of this study. The two primary research questions, along with their secondary counterparts, are as follows:

1. Does undergraduate students' prior exposure to three elements of computer usage – software awareness, video game experience, and social media usage – in combination with their perceived and demonstrated spatial skills, allow for the classification of students into stable groupings which can then function as student profiles?
    a. If the answer to question one is affirmative, how many profiles are optimally identified within the analyzed sample of students?
    b. If the answer to question one is affirmative, what are the membership statistics for the number and ratio of students attributed to each profile?
    c. If the answer to question one is affirmative, what are the stable characteristics of each of the student profiles?
2. Can in-depth exploration of the nature and frequency of identified undergraduate student behaviors, in combination with student profile membership and virtual

environment spatial configuration, yield insight into the likelihood of behavioral occurrences during an information-based learning task that takes place in a virtual environment?

a. If the answer to question two is affirmative, what is the nature of the behavior employed by an individual with each occurring combination of student profile membership and placement within spatial condition?
b. If the answer to question two is affirmative, are there underlying implications that can be suggested by a review of relevant literature?
c. If the answer to question 2b is affirmative, what potential directions for future research can be generated?

This study applies a multi-stage approach using both quantitative and qualitative analyses in the attempt to explore the impact of student characteristics and spatial configuration on behavior while completing an information-based task within a virtual environment. Exploration of these possibilities involved having students participate in a learning task within one of three virtual environment spatial conditions, in addition to completing three premeasures related to computer experience and spatial skill. Cluster analysis was used to analyze the data, revealing four distinct student profiles

A case study method was used to explore the data of a subsample of nine participants who had their computer screens video-recorded during their participation in the virtual environment. Behaviors observed on the videos were then coded, quantified, and discussed within the context of student profiles, spatial condition, and cohort comparison. Research question 2c was both asked and answered within the context of a review of literature which identified additional, potentially related, constructs.

The broader goal of this research is to facilitate an understanding of how students choose to conduct themselves when faced with an information-based (education-oriented) task within the seeming 'freedom' of an online environment not dissimilar to that in which many students spend much of their downtime. It is anticipated that by increasing the understanding of who students are – in this case, their perception and demonstration of navigational proficiency, as well as technology usage pattern – and how these characteristics consistently impact performance, it will become increasingly possible to classify certain student characteristics as contributors toward increased performance, and others as detractors from it. This capacity will help to increase the possibility of designing future learning activities in a manner that is customized to the now-defined strengths – or challenges – of a particular cohort.

Furthermore, it is hoped that by studying student behavior within the context of the 'physical' construction of a virtual environment – in this case, spatial configuration – it will become increasingly possible to create future environments that are optimized for the provision of superior (if subtle, and often unrecognized by the learner) support to help leaners reach the ultimate goal of all education-based virtual environments, that being the knowledge or skill acquisition.

Much literature exists on the use of virtual environments as platforms for various types of learning activities, and some study has been conducted on the behavior of individuals within a virtual environment. However, both of these concentrations are representative of a relatively new field of study and, as might logically be anticipated in a new field of study, it would make sense for the net to initially be cast wide and the focus of study to start out by encompassing a broad perspective. Over time, as a body of literature begins to accumulate and the need for a general sense of 'footing' within the field has been satisfied, the basis for a collective understanding begins to develop. At this point in the evolution of the field, it makes sense that the focus of study will start to become more targeted as researchers move on to investigate specific questions raised during the broad-spectrum studies.

It is at this point in the development of the still-emerging field of study regarding virtual environments that the current study is occurring. As such, very little – if any – study has thus far been conducted on the intersection of learning in virtual environments and the implications of the avatar navigation and/or camera manipulation of students within them. That intersection is the actual behavior of students during completion of a learning task within a virtual environment. It is at this intersection that the current study hopes to make a contribution to the body of knowledge; one which will help to fill this gap in the literature and inform future practice with regard to the use of virtual environments as platforms for learning.

Literature Review

There is a need for the field of education to look at the behavior of students as a way to begin understanding how best to adapt the delivery and content of learning opportunities in a way that once again captures learners' attention and harnesses their motivation. (Prensky, 2006). As such, educators are looking at the technology that is voluntarily used by students outside of the classroom as a way to better engage students inside the classroom (Bauer, 2007, Broussard, 2009, Grosch, et al., 2014). However, this course of direction unleashes a host of unanswered questions with regard to the best manner of implementation, especially because technology continues to develop at a rapid pace (Martenstyaro & Rosmansyah, 2015) that far outstrips development of the very policy and procedure that must support technology's importation into the classroom. It is also a concern that students very often adopt these new technologies at a much faster pace than their instructors (Bauer, 2007, Grosch, et al., 2014). Therefore, in the pursuit of developing effective ways to implement new methods of education, it becomes important to first get a good sense of the available technology, determine the implications of how it is formatted for use, and – most importantly – develop a strong understanding of the students, themselves, who have been described as "no longer the people our educational system was designed to teach" (Prensky, 2001, in Bauer, 2007, p. 2924).

Virtual Environments

Virtual environments are sometimes referred to as *virtual worlds* (Hanewald, 2013, Martenstyaro & Rosmansyah, 2015) or *virtual displays* (Loomis, Blascovich, & Beall, 1999). Virtual environments are computer-generated (Allahyar & Hunt, 2003), three-dimensional (Cromby, Standen, & Brown, 1996), persistent digital environments. Users navigate through virtual environments via the manipulation of three-dimensional "virtual selves" (Martenstyaro & Rosmansyah, 2015) that look and act like human beings (Bombari, et al., 2015). These "on screen personas" (Hew & Cheung, 2010) are known as *avatars*. Depending on the design of the virtual environment, avatars can be enabled to communicate through non-verbal gestures, and to move through the environment by appearing to walk, fly, or teleport from place to place within the environment (Hanewald, 2013). Two types of avatars populate virtual environments. The first is a *human-avatar* (Bombari, et al., 2015) that has no autonomy within the virtual environment except for what is provided by the human who is controlling the avatar. The second type of avatar is the *agent-avatar*, whose actions within the environment are entirely computer-controlled (Bombari, et al., 2015). The presence and nature of avatars is of significant importance when designing a virtual environment that is intended to engender "natural" (Bombari, et al., 2015, p. 3) human behavior from its users, for it has been determined that individuals will begin to take on behavior that 'matches' the physical representation of their avatar (Lam & Riedl, 2011). When the avatars populating a virtual environment are of a highly realistic nature – thereby looking and acting much like real-world humans do – the behavior of the human participants who are participating in the environment is also more natural (Bombari, et al., 2015).

Virtual environments are often mistakenly thought of as being interchangeable with virtual reality (VR) (see *Literature Review* section, *Virtual reality* subsection) or video games (see *Literature Review* section, *Video games* subsection), and they are easily confused with Virtual Learning Environments (VLEs), which are otherwise known as Learning Management Systems (LMSs) (see *Literature Review* section, *Virtual learning environments subsection*). Much of the confusion regarding this interchange of terms arises from the typical practice of situating virtual learning environments, virtual reality applications, and video games within the platform of a virtual environment. However, significant distinctions exist between the four applications of technology, and it is important to clearly distinguish between them in order to unambiguously identify the technology that was used – and not used – in the current study. The current study utilized a virtual environment (as opposed to a VLE/LMS) as the delivery platform for an information-based task. Virtual reality and video games were not employed within the virtual environment used for the current study.

Virtual learning environments. *Virtual learning environments* are interactive learning environments that are often used to implement online learning components of a structured educational program (Rienties, Giesbers, Lygo-Baker, Ma, & Rees, 2016). Virtual learning environments are typically managed by a learning management system (LMS), an “indispensable tool” (Yasar & Adiguzel, 2010) that provides resources to facilitate the work that takes place in a virtual learning environment (Hampel, 2014); the two types of technology are sometimes referred to interchangeably (Yasar & Adiguzel, 2010). Berking and Gallagher (2013, in Dobre, 2015) defined a learning management system as "a key enabling technology for "anytime, anywhere" access to learning content and administration" (p. 320). Blackboard Learn (a proprietary learning management system) and *Modular Object-Oriented Dynamic Learning System* (MOODLE, the most commonly used open-source system) (Cavus & Zabadi, 2014) are two well-known platforms that are frequently used by academic institutions (Dobre, 2015, Rienties, et al., 2016, Simkova & Stepanek, 2013), while lesser-known learning management systems include Docebo (a Cloud computing-based system) (Dobre, 2015) and the hybrid *Simulation Linked Object Oriented Dynamic Learning Environment* (SLOODLE) which combines a learning management system with a three-dimensional virtual environment (Martenstyaro & Rosmansyah, 2015, Yasar & Adiguzel, 2010). Learning facilitators or instructors may use virtual learning environments to facilitate content delivery, announcements, assignments, student assessment, and interpersonal interaction such as communication between instructor and student (Hampel, 2014, Ramirez-Correa, Rondan-Cataluna, Arena-Gaitan, & Alfaro-Perez, 2017, Simkova & Stepanek, 2013), and discussion forums (Cavus & Zabadi, 2014, Rienties, et al., 2016), along with collaborative activities such as video-conferencing, group meetings, blogs (Shoonenboom, 2014, in Hampel, 2014), chats, meet-ups, or the creation and maintenance of wikis.

Virtual reality. *Virtual reality* (VR) is an advanced and complex application of technology that takes place within a virtual environment (Loomis, et al., 1999). Many different terms have been used to define virtual reality, and it is helpful here to spend time exploring some of these terms as a way to understand how virtual reality is distinguishable from a virtual environment. For example, some terms commonly associated with virtual reality are *immersion,* *immersive,* or *immersed* (Bombari, et al., 2015, p. 2). These terms relate to the concept of having a type of experience that feels as through users are conducting their online activities "in the real world" (Bombari, et al., 2015, p.2).

Allahyar and Hunt (2003) describe an immersive virtual experience as one where the user's visual sensory input is restricted to the vantage proffered within the virtual environment, while Ludlow (2015) explains that a "true virtual reality tool" (p. 3) facilitates a completely artificial experience. As such, users of virtual reality will experience a virtual environment in a very unique way because of virtual reality's high level of sensory fidelity (Waller, Knapp, & Hunt, 2001). Waller, Hunt, and Knapp (1998) use the term "fidelity" (p. 130) to describe the degree to which virtual reality is "indistinguishable" (p. 130) from its real-world counterpart. Juul (2011) concurs, describing the experience of immersive virtual reality as "completely absorb[ing] … *as* [though it were] *a real-world activity*" (p. 190).

The term "desktop virtual environment" (Allahyar & Hunt, 2003, p. 265) is used by the authors to describe an experience where the user retains their ability to see their real-world surroundings while also viewing the virtual environment as displayed on their computer or other device. Ludlow (2015) uses the term "mixed reality" (p. 3) to describe a virtual experience where the user continues to be immersed in the sensory input of their physical environment, while also engaging with the visual and auditory input occurring within the on-screen environment.

For the purposes of the current study, use of the term *virtual reality* will be intended to encompass Ludlow's (2015) concept of *true virtual reality* (p.3), along with Allahyar and Hunt's (2003), Bombari, et al.'s (2015), and Juul's (2011) collective concepts of *immersion*. Use of the term *virtual environment* (sans virtual reality) within this study will be intended to be inclusive of Ludlow's (2015) concept of *mixed reality* (p. 3) and Allahyar and Hunt's (2003) definition of *desktop virtual environment* (p. 265).

To further delineate the concepts of virtual environments and virtual reality, it is helpful to understand that virtual reality typically utilizes specialized equipment (Allahyar & Hunt, 2003) – such as a head-mounted display (HMD) or headphones (Bombari, et al., 2015), goggles, and/or gloves – to facilitate a fully immersive sensory experience by isolating the user from the sensory input of their real-world environment while substituting alternative sensory input that 'matches' the events occurring within the environment and incurs a subjective feeling of *presence* (Bombari, et al., 2015, p. 3) in the virtual environment. Although engagement with virtual reality is becoming increasingly more widespread as the necessary specialized equipment becomes more affordable (and thereby, more accessible), it is highly commonplace for virtual environments to be used without the addition of virtual reality.

Video games. In similar vein, although video games also commonly take place within virtual environments, it is important to note that virtual environments are not synonymous with video games. Simply put, at its core, a video game is a game, and its users are thereby game players. Juul (2011) defines a video game as a game that takes place on a video screen and has rules that are enforced by a computer of some type. Although it could be argued that the concept of *gameplay*, defined by Ang, Avni, and Zaphiris (2008) as "strategies and motives of the player" (p. 534) or "activities conducted within a framework of agreed upon rules that contribute directly or indirectly to achieving goals" (p. 535) could apply equally well to the user of a virtual environment as to the player of a video game, there is an important divergence with regard to the purpose and nature of the engagement. Video games are distinguished by the presence of defined outcomes and goals that players work toward (Juul, 2011), along with the presence of specified win/lose *ludus* rules that are established as a way to define how – and by whom – a game is won or lost (Ang, et al., 2008, Salen, 2007). Another distinction of games is that they encompass some form of competition, be it between players, between a player and the game, or between players and themselves (Reiber & Noah, 2008).

These distinctive characteristics are not true of a virtual environment, however, as it is simply a computer-generated environment, governed by the much broader *paidea* rules of environmental design that are established – almost by default – simply as a result of the existence or nonexistence of features within the virtual environment. Paidea rules thereby limit or expand the opportunities for interaction with, or within, that environment (Ang, et al., 2008). Users are able to manipulate avatars to explore and interact with other users and with the environment, itself. As such, the user's exploration and interaction are not directed by externally defined rules, goals, or objectives, and there is no win/lose condition; rather, users' use of the virtual environment is unfettered and delineated only by the technical limitations of the environment and the individual intent of the user.

Parallels between virtual environments and video games. Having distinguished between the unique characteristics of video games and virtual environments, it is also important to recognize that many of the attributes of video games that can cause them to be highly effective mediums for education (Gee, 2013a, Gee, 2013b) also hold true when using a virtual environment as a platform for learning. For example, video games, like all games, can be highly motivational (Holmes & Gee, 2016) and the same aptitude for motivation also holds true for virtual environments. (Ludlow, 2015).

One of the unique attributes of video games is the unusual capacity to invoke learning without necessarily requiring conscious effort (Gee, 2005b). Reber (1993, in Rieber & Noah,

2008) is a proponent of this type of subconscious learning, using the term *tacit* to describe learning that is done “below one’s awareness level” (p. 85) and thereby occurs without intentional effort on the part of the learner. Virtual environments possess a parallel aptitude by virtue of their ability to offer users “meaningful new experiences… [with] the potential to make people smarter and more thoughtful” (Gee, 2005b, p. 6).

Video games with the ability to inherently facilitate learning are able to make knowledge and skill development easily accessible to a wide variety of learners who possess an even wider variety of learning preferences (Gee, 2005b). This broad accessibility of knowledge and skill development can be further facilitated by offering multiple and variable opportunities for goal attainment within the game (Gee, 2005b). Virtual environments naturally facilitate this same type of variability by providing users with extensive opportunity for exploration and low-risk trial-and-error learning; in turn, this freedom stimulates a metacognitive process as learners begin to discover and ponder their own preferences and proficiencies with regard to thinking and learning (Gee, 2005b).

Salen (2007) points out that video game players operate as “researchers” (p. 302) because of the necessity of reflecting on their previous decisions and then using that backward perspective to determine their forward movements within a game. This type of reflection also naturally occurs when a user of a virtual environment interacts with that environment and begins to discover what type of possibilities are open to them. Interestingly, that initial exploration acts like the proverbial stone thrown into the still-water pond, as it inadvertently starts to create an ever-expanding ripple effect of experimentation and discovery that lead to even greater learning effectiveness. As this process grows, the learner inevitably begins to determine the current and future implications of their actions within the virtual environment, thus engaging in a process of analysis and synthesis that intensify the scope of their learning (Salen, 2007).

Virtual Environments as Platforms for Learning

There exists a substantial body of literature examining various elements of learning within a virtual environment. For example, one of the key premises for using a virtual environment as a learning platform is the expectancy that the skills learned in a virtual circumstance will be transferable to a real-world counterpart (Waller, et al., 1998, Williams, Narasimham, Westerman, Rieser, & Bodenheimer, 2007). Hanewald (2013) points out that the seemingly-limitless customizability of virtual environments allows them to function as a mirror-images of real world situations. This capacity for emulation, in turn, facilitates the development of real-world skill development, but without the presence of real-world risks (Hanewald, 2013).

Intrinsic learning motivation occurs when an individual takes an authentic interest in a subject and is personally motivated to pursue deeper learning of that topic, regardless of external expectations (Kyndt, Dochy, Struyven, & Cascallar, 2012). *Autonomous motivation* occurs when a learner takes ownership of a concept and is intrinsically motivated to continue engaging with that concept at a deeper level (Baeten, Dochy, & Struyven, 2012). Gee (2005b) suggests that a key part of facilitating ownership – and with it, the opportunity for learning material to make a lasting change within the learner – is the development of an identity that encompasses the desired “values, attitudes, and actions” (p. 8) which are inherent to the learning activity. Virtual environments offer natural support to identity development through the embodiment and manipulation of avatars, and Gee (2005b) points out that the more engaged a virtual environment user is with manipulating ‘their’ avatar, the greater their investment in the learning environment and the educational concepts presented therein. Supporting this idea of engagement through avatar representation, Herold (2010) found that students participating in a supplemental online activity (designed to augment the traditional classroom delivery of a media studies course at a Hong Kong post-secondary institution) chose avatars that were indicative of the desire for individual identities. During an introductory session for a supplemental online activity in the Second Life virtual environment, the author introduced the use of avatars to students and asked students to create an avatar that would function as an "online representation of themselves" (Herold, 2010, p. 793). Although the students were of Asian descent and evidenced very similar coloring and features, along with quite a homogenous physical stature, Herold (2010) discovered that not one of the participants chose to represent themselves as Asian during their participation in Second Life. Rather, students verbalized their intent to pursue an online identity unique to their participation in the Media studies course (Herold, 2010). Review of the students' later comments regarding their engagement in the supplemental online activity indicated that they were highly satisfied with their experience, and felt that the quality of learning was high.

Along with parallel concepts such as play and happiness, fun is considered to be motivational in learning (Reiber, 1996), and Gee (2008) goes so far as to state that video games "recruit learning in the service of play" (p. 231). An interesting take on this idea is the proposal that the fun of a game is directly related to the player's development of competency in solving the problems presented within it (Gee, 2008). This idea is given further credibility by Rieber and Noah's (2008) study, which found that participants' enjoyment of the gamified learning activity increased in proportion to their competence in navigating the game. Laski and Siegler (2014) also suggested that a more challenging learning activity may be more engaging than one that was simpler to achieve. Simple deduction would then suggest that the presence of problems, coupled with the capability to solve them, can act as an independent source of learner motivation. Reiber and Noah (2008) inject a note of caution into this discussion, however, explaining that if a learner cannot gain a good grasp of the problems posed by their learning environment, the frustration that they subsequently experience is likely to work in the opposite manner and become a barrier to learning, instead.

However, it is also important to note that in their study of using games for learning, Reiber and Noah (2008) found that delivering content via games was not necessarily a guarantee of increased knowledge acquisition, for, although student enjoyment of their gaming activity was high, in some cases, the gaming activity actually interfered with participants' ability to learn explicit information and decreased their sense of assurance with regard to their own comprehension. The authors' recommendation was that educators who wish to use games for content delivery need to ensure that they are carefully evaluating whether their students are, in fact, acquiring the actual content (and context) that was intended. Rieber and Noah (2008) also strongly recommended that games not be an independent source of content delivery, but that learners also be consistently supported through instruction from an "outside agent" (p. 90). Grosch et al. (2014) offer a similar caution, pointing out in their analysis of student achievement and interaction with various types of media (including video games) that delivering learning content via media formats does not ensure an increase in the acquisition of information.

Learning Ventures in Virtual Environments

As virtual environments have gained notoriety in the vast arena of education, the variety of applications for their use has exponentially mushroomed in scope. In their meta-analysis of the literature exploring the use of virtual environments for the purpose of learning, Reisoglu, Topu, Yilmaz, Yilmaz, and Goktas (2017) found that collaborative applications were the most commonly implemented. The following examples of learning activities that have been field-tested in a virtual environment represent only a very small sampling of the diverse array of innovative educational uses that have been developed in recent years.

Facilitating learning for individuals living with learning challenges. Virtual environments have been studied for over two decades with regard to the "exceptionally valuable … effective, affordable, accessible, and safe" (Cromby, et al., 1996, p. 489) learning opportunity that they can provide to individuals who are living with learning disabilities. Similarly, virtual environments have provided invaluable learning opportunities for individuals who are living with intellectual disabilities, offering "enjoyable repetition" (Standen, Brown, & Cromby, 2001, p. 290) and the provision of challenges that gradually increase in tandem with skill development (Standen, et al., 2001). Along similar lines, Gregg, Chang, and Todd (2012) examined the value of using an innovative virtual environment platform – complete with the use of avatars and the provision of e-mentoring, academic support, research, and social media integration – as an effective learning tool for adults who aspired to study for careers in science, technology, engineering, or mathematics (STEM), but were living with literacy barriers that made such study difficult to achieve.

Collaborative learning in virtual environments. Researchers have extensively studied the value of the collaborative learning opportunities that can be facilitated within a virtual environment (Bronack, Riedl, & Tashner, 2006, Chang, et al., 2009, Hanewald, 2013). For example, a number of studies have been undertaken on the benefits of using virtual environments as a setting within which to engage in communication (Hew & Cheung, 2010). In their meta-analysis on the use of virtual environments for educational purposes, Reisoglu, et al. (2017) found that collaboration and communication were two of the most highly prized skill sets when it came to the design of learning activities.

Language learning in virtual environments. Virtual environments appear to be particularly well-suited to the facilitation of instruction or practice in a second language (Hew & Cheung, 2010). Indeed, in their meta-analysis of learning in virtual environments, Reisoglu, et al. (2017) determined that language learning was not only one of the three most prevalent educational topics studied within a virtual environment, it was also one of the three primary cognitive skills most commonly obtained. Interestingly, the other two most commonly acquired cognitive skills were engagement and communication (Reisoglu, et al., 2017), both of which could certainly be considered essential components of learning a language. In their study of language learning within a virtual environment, Garrido-Inigo and Rodriguez-Moreno (2015) explained that when an individual is engaging with a virtual environment via avatar representation, “the division between the physical world and the fictitious world disappears” (p. 453). The authors argued that this blurring of lines between what is ‘real’ and what is ‘not’ was to the advantage of the instructor, who was then able to coach students in the target language in a manner that was not perceived by the learner as impinging upon their autonomy (Garrido-Inigo & Rodriguez-Moreno, 2015), thereby contributing to a lower sense of risk. This sense of autonomy then served to encourage learner engagement that was less self-conscious and more open to engaging with the educational content (Garrido-Inigo & Rodriguez-Moreno, 2015).

Distance education in virtual environments. Conducting distance education within a virtual environment offers both students and teachers the opportunity to make meaningful connections – to “belong to a community of learners” (Hanewald, 2013, p. 244) – that aren’t facilitated in the same way through the use of asynchronous online resources and textual communication (Bronack, et al., 2006, Hanewald, 2013). Expanding on this concept, Hanewald (2013) also points out that using a virtual environment for learning delivery makes it possible for socialization amongst classmates to take place across a very broad definition of 'distance', thereby facilitating socialization (Urso & Rodrigues Fisher, 2015) and collaborative learning – much akin to that which occurs in a physical classroom – to take place amongst classmates who are participating in class together online while still retaining diverse, and often far-flung, physical and cultural settings.

Supplemental course content in virtual environments. In their review of 167 empirical studies of virtual environment applications in education, Reisoglu, et al. (2017) found that Second Life was one of two most commonly utilized three-dimensional virtual environments for developing supplemental course content. Herold (2010) studied the efficacy of using the Second Life virtual environment as a supplemental learning tool for a regular classroom-delivered course on Media studies at a post-secondary institution in Hong Kong. The author concluded that virtual learning activities are facilitative of student learning if the online activities are well integrated with classroom learning and "sufficiently contextualized" (Herold, 2010, p. 792) within the broader scope of the offline course.

Simulations in virtual environments. Hew and Cheung (2010) examined the effectiveness of virtual environments when designed to accurately mimic real-world environments such as a simulated post-secondary campus that can allow individuals (e.g. international students) to spend time familiarizing themselves with the virtual campus long before setting foot on the real one. Because virtual environments can be designed to mimic situations that are impractical, costly, or unsafe to regularly engender in real-life, they have become a go-to resource for the construction and implementation of simulation training or activities (Reisoglu, et al., 2017). Researchers have found virtual environments to be of great benefit for use as experiential training simulations for a diverse array of faculties such as nursing

(Urso & Rodriguez Fisher, 2015), engineering (Maratou, et al., 2016), emergency services (Cohen, et al., 2013), science, and ethics (Nadolny, Woolfrey, Pierlott, & Kahn, n.d). One of the strengths of learning facilitation in a virtual environment is the capability to participate in collaboration with other learners (Reisoglu, et al., 2017), making the practice of skills sets based in teamwork a highly manageable endeavor.

The use of virtual environments for training in skill development is rapidly growing because of a virtual environment's capacity for providing learners with the opportunity to encounter same problems that occur in real-world situations (Maratou, et al., 2016) and to "learn by doing" (Hew & Cheung, 2010, p. 37). Learning by doing – otherwise known as 'live exercises' – is the "gold standard" (Cohen, et al., 2013, p. 78) for gaining the essential practice necessary for effective execution during many real-world situations. Using a virtual environment, precise representations of scenarios can be generated to allow learners to feel as through they are "actually … there" (Maratou, et al., 2016, p. 898) within targeted real-world situations (Urso & Rodrigues Fisher, 2015) that would otherwise be extremely costly, very difficult to orchestrate, or impossible to consistently replicate for repeated practice (Cohen, et al., 2013, Hanewald, 2013, Hew & Cheung, 2010, Urso & Rodrigues Fisher, 2015). Virtual environments can promote greater engagement with educational concepts by offering a highly accessible "substitute for actual exploration of the real world" (Waller, et al., 1998, p. 129) and providing repeated opportunity for the development of targeted skill sets (Cheng, 2014, Ludlow, 2015).

Preservice teacher training in virtual environments. Study has demonstrated that preservice teacher training completed in a virtual environment was equally as effective as conducting the same type of skill practice through the traditional role-play methods (Dawson &

Lignugaris-Kraft, 2013), or in a real-world classroom setting (Whitten, et al., 2013, in Ludlow, 2015). For teachers, one of the most challenging – and most vital – skill sets to develop is the ability to successfully navigate teacher-student interactions within the classroom. Virtual environments provide a low risk opportunity for preservice teachers to encounter and respond to a wide variety of challenging situations, and to take a second (or third) run at scenarios that would benefit from repeated practice. simSchool (Ludlow, 2015) and TLE TeachLivE™ (Dawson & Lignugaris-Kraft, 2013). are examples of virtual environments that have been used effectively for the specific purpose of promoting the learning of preservice teachers by allowing them to interact with virtual students. Preservice teachers who participated in these learning applications were able to generalize the proficiency gained in the virtual classroom to an increased competency when working with their students (Dawson & Lignugaris-Kraft, 2013). In addition, they also came away from the virtual environment training having developed a heightened awareness of student behavior, and a greater sense of professional competency (Ludlow, 2015).

Theories of Learning

A number of theories of learning were investigated in relation to the current study of learner behavior during an information-based task that took place in spatially-diverse virtual environments. However, the complex, unique nature of the current study and its position within a still-emerging field of research caused it to be somewhat 'orphaned' when it came to situating the study neatly within a long-established theory of learning. Indeed, every time an attempt was made to do so, the current study seemed to pop a theoretical arm or leg 'out of the box'.

Situated cognition. Even before virtual environments began to emerge as more than a novelty on the technology scene, Brown, Collins, and Duguid (1989) discussed the idea of *situated cognition*, pointing out that separating cognitive knowledge from its environmental context can create many difficulties with regard to retention and application of that knowledge. Using a virtual environment to deliver knowledge content is a natural way to resolve this concern because of the environment's almost unlimited capacity to be customized in a way that supports knowledge retention and application by matching the knowledge content with the context of the information delivery (Allahyar & Hunt, 2003).

In addition to this natural capacity for fitting context to content, Gee (2005b) points out that emphasizing smaller key elements of larger concepts can prevent a learner from becoming overwhelmed with the sheer volume of information encompassed by a larger, more complex concept. Using a virtual environment as the platform for content delivery facilitates customization of the amount of information that is presented at any given point in the learning process. It is the concept of situated cognition that undergirds the use of virtual environments for the conduction of simulations (see *Literature Review* section, *Simulations in virtual environments* subsection).

The theory of situated cognition was helpful when investigating the use of virtual environments for simulations that were meant to mimic real-world situations with a high degree of fidelity. However, although situated in an environment described to participants as a 'museum' and featuring historical information, the current study was not intended to be a simulation, and participants were not expected to learn or practice behavior appropriate to a museum environment.

Context-dependent learning. Gershman (2017) explained that learning always takes place within the presence of "background stimuli" (p. 557) that form the context within which the learning occurs. When the learning context of new information is similar to where the application of that learning will take place, the new knowledge or skills are more easily transferred. The use of virtual environments for knowledge or skill acquisition can support the acquisition of the same skills in the natural environment, as once learned in the virtual representation, it can be expected that there will be a "savings" (Crossley, Ashby, & Maddox, 2014, p. 1) in the amount of time or practice needed to replicate the learning process in a real-world application. This theory of learning is important with regard to the rationale and validity for conducting simulations in virtual environments for the purpose of later replication of knowledge or skill sets in real-life. However, the objectives of the current study do not include a delayed replication of the historical knowledge gained during the information task. As such, context-dependent learning theory does not carry strong application for the current study.

Constructionism. The theory of constructionism is one that has logical connections to learning within virtual environments. First introduced by Seymour Papert, constructionism is based on the premise that constructing "tangible" (Boytchev, 2015, p. 355) artefacts will facilitate the development of mental understanding. Papert is said to have advocated for the inclusion of information technology in the classroom as a way to construct artefacts (Boytchev, 2015) and virtual environments – especially those used for learning through simulation of real-world situations – are often designed to offer a plethora of 'virtually tangible' artefacts that can be creatively manipulated to deconstruct and reconstruct ideas within the environment. However, in the current study, participants were not given the freedom to manipulate objects within the virtual environment, nor were they provided with the ability to generate new artefacts.

Constructivism. Constructivism is an approach to education that is largely collaboration-based, with a focus on the generation of new knowledge through active creation of knowledge or ideas (Hasan Kahn, 2013). As succinctly explained by Ertmer and Newby (2013), constructivists postulate that "Humans *create* meaning as opposed to *acquiring* it" (p. 55).

However, in the current study, learners were not provided with opportunity to collaborate with one another, nor with computer-controlled *agent-avatars* (see *Literature Review* section, *Virtual Environments* subsection). This lack of collaboration violates an essential criterium of constructivism (Hasan Kahn, 2013). Although argument can certainly be made that participants in the current study are "creating meaning from experience" (Bednar, et al., 1991, in Ertmer & Newby, 2013, p. 55) by generating their own knowledge and ideas through a trial-and-error exploration of the *paidea* rules of the environment (see *Discussion, Part III* section), it must be recognized that this is a somewhat weak and one-dimensional application of the foundational tenets of constructivism.

Behaviorism. B. F. Skinner's theory of "radical behaviorism" (Skinner, 1963, p. 951) is rooted in biology and based on the belief that behavior is essentially a response to an antecedent provided by the environment: provide the appropriate environmental stimuli or reinforcement, and the corresponding behavior could be anticipated to occur as a result (Skinner, 1985). As Skinner (1985) puts it, "the environment *selects* behavior" (p. 291). As such, behaviorism was a necessary theory to consider with regard to the impact of three different environmental spatial conditions on behavior, as explored within the current study. For example, behaviorism raises the question of whether placing a participant into a particular spatial condition could be associated with the expectation of a consistent pattern of behavior that was specific to that condition.

However, the current study posed some obvious difficulties with regard to applying the theory of behaviorism for a reason somewhat opposite to that of the problems encountered when trying to apply constructivism: the design of the current study gave learners too much freedom within the virtual environment. For example, learners were not actively directed toward a particular outcome, or to a desirable set of behaviors through the use of reinforcement. Rather, learners were given complete freedom to navigate the virtual environment according to their own personal preferences and strategies. Indeed, without this freedom to engage in various behaviors within the environment (e.g. to negatively or positively economize; see *Discussion* section, *Negative economizing* and *Positive economizing* subsections, respectively), much of the premise of the current study would be nonexistent.

Moderate constructivism. Moderate constructivism is a very young theory based on the dilemma that "interpretations change the works of which they are interpretations … they change the properties of those works" (Stecker, 1997, p. 44). In his analysis of Stecker's theory, Percival (2000) delineates moderate constructivism into two camps: a *strong reading* of the theory, and a *weak reading*. A strong reading declares an unequivocal "dependence of properties" (p. 51), stating that, without exception, every interpretation of an entity will inherently alter its properties. However, a weak reading qualifies this absolute position by proposing that only a portion of associated interpretations will impact an entity's attributes (Percival, 2000).

When relating this theory of learning to the current study, it helps to recognize that according to Grosch, et al. (2014), moderate constructivism suggests that a learner's success is not determined by external evaluation but is, instead, generated by a combination of the learner and the learning environment. This concept holds a certain amount of parallel to mainstream constructivism, which states that the creation of meaning is dependent on the interaction between the two "critical" (Ertmer & Newby, 2013, p. 55) variables of learner and learning environment. However, while the constructivist learner actively creates new knowledge which then contributes to the nature of acquired learning (Hasan Kahn, 2013), the moderate constructivist learner actively "measure[s]" (Grosche, et al., 2014, p. 796) the quality and value of a learning experience, which then contributes to the attributes of the learning experience.

Summary of Learning Theories. Although a number of learning theories are partially applicable to the current study, a 'perfect fit' has not yet been determined. This may be attributed to the emergent nature of the current study, which – rather than being firmly situated within one discipline – draws from different fields of study and brings them together in order to study the behavior (psychology) of learners (education) within a virtual environment (computing science technology).

Research Methods

Three primary research methodologies are typically used for research in education: the quantitative method, the qualitative method, and the mixed method. All three methods focus on the same basic process of identifying a research problem and asking a research question (sometimes posed as a hypothesis), collecting related data, and analyzing the data to help provide an answer to the research question (Creswell, 2015).

Quantitative research method. The term *quantitative* originates from the concept of *quantity* (https://www.merriam-webster.com/dictionary/quantitative). As such, quantitative research focuses specifically on measuring differences in the quantity of something (Evans & Rooney, 2014). For example, a quantitative research study may make comparisons or use an instrument to measure (Creswell, 2015) increases, decreases, or lack thereof, in frequency, volume, or time, which are then expressed numerically (Evans & Rooney, 2014). A testable, falsifiable hypothesis is generated as part of the basis of the study, and is based on the anticipation of a particular outcome of the statistical analyses of the data (Creswell, 2015). Assessing whether a variable or factor may predict an outcome is a process that sits firmly within the camp of quantitative research methodology, as quantitative research designs are often prompted by the desire to explain the relationship between one variable and another (Creswell, 2015). As such, quantitative designs are often experimental (wherein a variable is manipulated in order to explore its impact on something), but quantitative research may also be correlational (wherein a non-causal relationship is identified), or survey-based (Creswell, 2015). Regardless of the specific design, quantitative studies establish reliability and validity through the use of proven instruments and objective statistical analysis procedures, and by controlling for pre-existing variables that may confound the results by interfering with the impact of the specific variable that the study was designed to investigate (Creswell, 2015).

Qualitative research method. The term *qualitative* originates from the concept of *quality* and relates to the nature of something or the qualities that are inherent to it (https://www.collinsdictionary.com/dictionary/english/qualitative). As such, qualitative research focuses on discovering and describing the nature of an entity (Evans & Rooney, 2014). For example, a qualitative research study may investigate what an entity was like, the impact it had on its surroundings, or how it was perceived by those who experienced it (Evans & Rooney, 2014), however, qualitative research may (and often does) also take the form of grounded theory, or ethnography (Creswell, 2015). Grounded theory has been used in the fields of information systems (Wiesche, Jurisch, Yetton, & Krcmar, 2017), sociology, health studies, and business (Goulding, 2017) to facilitate the discovery and development of inductive theories (Wiesche, et al., 2017) as revealed by the simultaneous accumulation, coding, and analysis of data (Goulding, 2017). Ethnography has its roots in social and cultural anthropology, but has also been used in education, sociology, medicine, and business (Trnka, 2017). The process of ethnography involves extensive fieldwork during which the researcher becomes immersed in the studied community for a minimum of twelve months, conducting an open-ended combination of informal observation and formal conversation out of which a theory emerges (Trnka, 2017).

Qualitative research revolves around a central phenomenon or key concept and is well-suited to the exploration of a research problem rather than the confirmation or disconfirmation of a research hypothesis. The role of perspective is also very important in qualitative research design, as it is often the intent of the study to explore a phenomenon from a perspective other than the researcher's, and the perspective of participants is considered to be more directive than the external perspectives offered via a prior review of literature (Creswell, 2015). Rather than using statistical analysis to explain the results of a qualitative analysis, the results of a qualitative study are often "interpreted" (Creswell, 2015, p. 18) by the researcher and discussed in descriptive or narrative form (Evans & Rooney, 2014) that may feature categories or themes that help to organize or contextualize the findings (Creswell, 2015). Without the use of statistical procedures to establish reliability and validity, qualitative studies rely instead on conveying realism and credibility through open discussion of researcher interpretations and/or assumptions, along with extensive explanation of the complexity of the data gathering process and the research conclusions (Creswell, 2015).

Mixed method of research. Synthesis is a process in which contributors join forces and together form a unique, complex entity (http://www.dictionary.com/browse/synthesis). Mixed method research is not simply a circumstance in which quantitative and qualitative methods happen to co-occur as uneasy bedfellows within the same study. Rather, mixed method research is a highly intentional, stand-alone research paradigm resulting from a synthesis of qualitative and quantitative research methods which results in "informative, complete, [and] balanced research results … that generat[e] important research questions and provide warranted answers"

(Johnson, 2007, in Ross & Onwuegbuzie, 2010, p. 234). One way that these important research questions are facilitated is by the ability of a mixed method to employ not just the more closed-ended questions of the quantitative approach or the more open-ended questions of the qualitative approach (Creswell, 2015), but a combination that maximizes the best of both. The premise of mixed methods research is that a researcher can identify potential weaknesses of using quantitative or qualitative research methods with relation to a particular study, and then proceed to compensate for the weaknesses of one approach with the strengths of the other. The resulting research process may feature either the qualitative or the quantitative elements in a dominant role, or it may be designed in a way that equally weights both approaches (Ross & Onwuegbuzie, 2010). In sum, the mixed methods researcher works toward establishing a targeted research process of data collection and analysis that "yields complementary strengths and non-overlapping weaknesses" (Brewer & Hunter, 1989, & Johnson & Turner, 2003, in Ross & Onwuegbuzie, 2010, p. 235).

In summary, there are significant differences between quantitative and qualitative approaches to research methodology; however, the two methods are also highly complementary as a direct result of those differences. From this complementariness rose the mixed research method, which intentionally designs the methodology of a specific study in a way that allows the two research approaches to compensate for each other and dovetail into a single, powerful approach. Together, all three research paradigms provide an extensive undergirding for an ever-expanding breadth of study enquiry.

Profile Development

The classification of individuals into groups is an age-old practice which finds its origins in the biological sciences. Everitt, Landau, Leese, & Stahl (2011) posit that the process of classification is essential to the furthering of knowledge, citing a quote from von Linne that dates back to 1737: “All the real knowledge which we possess, depends on methods by which we distinguish the similar from the dissimilar. The greater the number of natural distinctions … the clearer becomes our idea of things” (1.1 Introduction section, para. 4). That von Linne’s (in Everitt, et al., 2011) quote has stood the test of time is unsurprising, as the quest for greater clarity around the nature of individuals is an active pursuit in education today.

Most student populations are large enough that to attempt the individual study of each student would almost immediately become unwieldy and overwhelming, with the large volume of results becoming very difficult to interpret or generalize. Yet, the days of ‘one-size-fits-all’ methods of education have fallen by the wayside as educators have increasingly become aware that a single approach to education delivery simply won’t meet the needs of the increasingly diverse body of students found in today’s schools (Baeten, et al., 2012). As such, the need for a research method that facilitates the corporate study of individual characteristics is paramount. Although no two individual students will be identical in all respects, it can be anticipated that most individuals within a student population will share a commonality of some nature. The uncovering of these commonalities, and the subsequent use of them to create homogeneous groupings, is at the heart of a classification process known as *profiling*.

A range of studies have endeavored to create targeted profiles of students in various types of learning situations (e.g. da Silva, de Fatima Nunes, Santos, Queiroz, & Leles, 2012, Sailesh, Lu, & Aali, 2016, Scherer, Rohatgi, & Hatlevik, 2017, Weber, Lee, & Dennison, 2015). For example, van Rooij, Jansen, and van de Grift (2017) examined the potential for identifying secondary (high) school students who are likely to do well in further education. Their study revealed five student profiles which incorporated characteristics contributory to post-secondary success: behavioral engagement, self-efficacy in effort, surface learning, deep learning, metacognition, self-regulated learning, need for cognition, academic interest, and self-efficacy in understanding (van Rooij, et al., 2017). In a study targeting similar constructs but taking somewhat of an opposite approach, Mattern, et al. (2012, in Olivera-Aguilar, Rikoon, & Robbins, 2017) looked at variables that contributed to post-secondary dropout rates. The authors created student profiles using the characteristics of high school grade point average, placement test scores, first-year post-secondary grade point average, and academic self-belief, along with the presence of interfering factors (e.g. part-time work) and demographic variables (Mattern, et al., in Olivera-Aguilar, et al., 2017).

Fernandez-Aviles, et al. (2014) identified student profiles using the five variables of age, gender, nationality, employment status, and university admission to investigate the contribution that each variable made with regard to the likelihood of student success in post-secondary distance education. Olivera-Aguilar, et al. (2017) also explored variables contributing to post-secondary student success, investigating the relationship between non-cognitive characteristics and first-year post-secondary grade point average. The authors used the ten characteristics of connectedness, text anxiety, sensitivity to stress, academic self-efficacy, organization, meeting class expectations, commitment to college goals, institutional commitment, institutional support, and barriers to success, which resulted in six distinct student profiles and revealed that students with strong non-cognitive skills achieved the highest GPA, while disengaged students earned the lowest (Olivera-Aguilar, et al., 2017).

In their study of student perceptions regarding the use of classroom lectures versus the implementation of case studies, Baeten, et al. (2012) developed student profiles based on a combination of student motivation and learning profiles to investigate differences in student achievement and their reports of positive experiences. Haase, Chen, Sheppard, Kolmos, and Mejlgaard (2013) surveyed engineering students in two different countries regarding their perceptions on the importance of possessing interpersonal and professional skills, along with their perceptions on the value of possessing capability in math and science. The authors used these perceptions to create student profiles that compared students between the two countries and provided insight into engineering student expectations (Haase, et al., 2013). Jurik, Groschner, and Seidel (2014) tabulated data on the student characteristics of cognitive ability, pre-knowledge of a targeted subject, interest in the targeted subject, and perceived self-efficacy in the targeted subject. Data analysis revealed that the student profiles predicted both intrinsic motivation for learning and students' depth of cognitive engagement (Jurik, et al., 2014). In their study of the impact of student profile on undergraduate students' approaches to learning and their perceptions of workload. Kyndt, et al. (2012) used the characteristics of working memory capacity and student motivation to create three student profiles. The authors found that students with high autonomous motivation tended to engage in deep approaches to learning, while students with high working memory capacity tended to use more surface approaches, even when workload was high (Kyndt, et al., 2012).

In summary, student profiling holds the potential to inform research and to surprise researchers. Developing a profile for the purpose of education takes the educator beyond the limitations of their own experience and expands the range of their expectations. It provides the educator with opportunity to see the 'bigger picture' of who students are on a corporate level and develop a broader picture of new directions and trends in education. Student profiles can be used as a framework to undergird the emergence of a more informed exploration of the student perspectives and the student behavior which lead to the very outcomes which are the currency of the modern education system.

Spatial Skills

Spatial skills are fundamental to our function as human beings. Effective spatial skills facilitate autonomy and allow for the creation of routine and the prioritization of time. When the navigation of an immediate environment has been mastered, emerging spatial skills can engender confidence and encourage the exploration of the next-larger environment, which results, over time, in an ever-widening opportunity to interact with the world and learn from it. As such, spatial skill is a crucial construct when looking at an individual's potential for learning.

Spatial cognition. Spatial cognition is defined as "the cognitive processes associated with the development of a comprehensive understanding of a spatial environment and utilization of that knowledge" (Wallet, Sauzeon, Larrue, & N'Kaoua, 2013, p. 1). Thorndyke and Hayes-Roth (1982) put the concept more simply, explaining spatial cognition as "the acquisition and use of knowledge about large-scale space" (p. 561). The *L-R-S model* further clarifies the concept of spatial cognition by providing an explanation of the process involved in spatial cognition: Procedural knowledge is gathered and related firstly to the ability to identify landmarks (L), then to an awareness of routes (R), and finally, to a survey-level (S) understanding of an environment which provides the capacity necessary to build a *cognitive map* which encompasses configurational information about the environment (Wallet, et al., 2013). Waller, et al. (1998) break this process down a bit further, explaining that the initial stage of spatial cognition is one of *familiarization* (p. 132), wherein the individual pays initial attention to individual landmarks that have no apparent relation to each other. Secondly, the individual begins to link these landmarks together into a sequence, thereby forming for themselves a *route* *representation* (Waller, et al., 1998, p. 132) of the environment. Lastly, if exposure to the same environment continues long enough, the individual's spatial understanding of the environment will progress to a point where they will understand the relationship between various landmarks without needing a route to connect them in sequence, thereby developing an intangible personal 'map' of the environment that is known as *configurational knowledge* or a *survey representation* (Waller, et al., 1998, p. 132). Wallet, et al. (2013) further delineate spatial cognition into two types of navigational strategies: *Route strategy* is related to an *egocentric* perspective that use one's body as a reference point for direct navigation of a route (Waller, et al., 2013) by locating objects according to the front/back, left/right, and up/down axes of the body (Howard, 1982, in Wraga, Creem, & Profitt, 2000). *Survey strategy* uses an *allocentric* representation to identify locations on a map (Liben, 1991, in Wallet, et al., 2013) using a "world-centred" (Wallet, et al., 2013, p. 1) perspective. It is important to note that Scholl (1993, in Waller, et al., 1998) raised the concern that navigators of a virtual environment are restricted in their field of view, which may place limitations on their ability to develop a survey representation of the virtual environment or to process the layout of the virtual environment from an allocentric perspective.

Spatial orientation. Spatial orientation is the ability to "orient oneself with respect to the environment" (Allahyar & Hunt, 2003). Considered to be a stand-alone key component of overall intelligence – one that differs significantly from other well-known key intelligence components such as verbal ability – spatial ability varies widely amongst individuals (Allahyar & Hunt, 2003). Spatial orientation skills involve "the ability to imagine how a stimulus array will appear from another perspective" (Kozhevnikov & Hegarty, 200, p. 746). Spatial orientation facilitates the ability to use an egocentric perspective to assess the location of unchanged objects in an environment after an alteration in the individual's location (Hegarty & Waller, 2004).

Configurational spatial knowledge is the specific understanding of the overall spatial relationships within an environment, and is applicable to both real-world and virtual environments (Waller, et al., 2001). Spatial knowledge acquired in a virtual environment has been determined to hold strong parallels to the spatial knowledge acquired in the 'real world' (Foreman, et al., 2000, Peruch, Belingard, & Thinus-Blanc, 2000, in Wallet, et al., 2013, Peruch &Wilson, 2004, in Wallet, et al., 2013, Richardson, Montello, & Hegarty, 1999, Witmer, Bailey, Knerr, & Parsons, 1996). For example, Waller, et al. (2001) found a positive predictive correlation (r = .73) between participants' spatial capability as demonstrated during navigation of a maze in a virtual environment, and their real-world ability to navigate a similar maze.

Manifestations of spatial skill. Hegarty, et al. (2002) concluded that the self-report Santa Barbara Sense of Direction Scale (SBSOD) was a strong indicator of real-world, large-scale navigational ability involving proprioceptive sensory engagement (motion) and survey representation such as route planning and giving verbal directions (Sholl, 1988), but was less indicative of navigational ability that involved assessment through visual sensory engagement alone (as demonstrated in a desktop virtual environment without the use of virtual reality), and that it was "unrelated [to] … [and] distinct [from]" (p.443) pen-and-paper spatial ability tests. Turano, et al. (2009) lent mixed support to this conclusion. The authors used the SBSOD to evaluate the correlation between perceived sense of direction and real-world driver behavior, finding that the levels of perception and demonstration were similar for the females in their study, but not for the males (Turano, et al., 2009). Hegarty et al.'s (2002) conclusion that the SBSOD is not correlational with paper-and-pen demonstrations of spatial ability was borne out in the current study when comparing results of the Spatial Orientation Task (a pen-and-paper task which measured demonstrated spatial skill) with participants' self-rated scores of perceived spatial skill on the SBSOD. Indeed, three of four student profiles – encompassing fully 84% of the participant sample – that were identified by cluster analysis of the premeasure scores demonstrated a noticeable disparity between participants' levels of perceived and demonstrated spatial skill (see *Results* section).

Some disparity also appears to arise when the results of Waller, et al's (2001) conclusion of a positive correlation between virtual environment and real-world navigation, is considered in conjunction with Hegarty et al.'s (2002) conclusion that there is a positive correlation between perceived and real-world navigation, but not between perceived and virtual navigation. This disparity appears to centralize itself within the existence of differences between virtual and real-world environments. The current study utilized a combination of premeasures intended to compare perceived real-world spatial skill with a paper-and-pen demonstration of spatial skill, after which the results were then employed in a manner designed to gain greater insight into participant behavior while navigating a virtual environment. As such, it is worth taking the time to review some of the differences that have been identified between various manifestations of spatial skill.

For example, Hegarty and Waller (2004) explained the differences between the spatial skills of *perspective-taking* and me*ntal rotation*, stating that the two skills are separate entities and should be measured as such. The authors defined *spatial visualization* as a spatial skill in which an individual is able to imagine the 'movement' of an object within a larger environment while the individual's own position remains static (Thurstone 1950, in Hegarty & Waller, 2004). *Spatial orientation* is defined as a skill in which an individual is able to imagine the 'appearance' of an object that has not changed its position relative to the larger environment, although the individual has shifted to different perspective (McGee, 1979, in Hegarty & Waller, 2004). As such, perspective taking tasks are related to demonstration of spatial orientation., while mental rotation involves “imagining movement relative to an object-based frame of reference, which specifies the location of one object (or its parts) with respect to other objects” (Kozhevnikov & Hegarty, 2001, p. 745).

Hegarty and Waller (2004) also discussed the differences between mental rotation and spatial orientation, explaining that psychometric studies of spatial ability have identified different types of spatial frames of reference or “mental spatial transformations” (p. 176) used in navigation. They go on to discuss the difference between an egocentric frame of reference that uses body positioning as a way to locate position in the environment (see *Literature Review* section, *Spatial cognition*, subsection), and a reference frame that uses the external, cardinal directions of North, South, East, and West (Zacks, Mires, Tversky, & Hazeltine, 2000, in Hegarty & Waller, 2004). In addition, the authors discuss the “strong dissociations” (Hegarty & Waller, 2004, p. 177) between the ability to make egocentric-based transformations, whereby navigation is based on positions relative to the first-person individual, and the ability to make “intrinsic” (p. 176) object-based transformations, whereby navigation is based on positions relative to an outside object. This is supported by the neurologically-based findings of Kozhevnikov and Hegarty (2001), who found that egocentric perspective transformations triggered cortical activity in the left parietal-temporal-occipital area of the brain, while object-based transformations (mental rotation) triggered posterior brain activity that was more intense on the right side of the brain than the left.

Spatial Learning in Virtual Environments

The ability to create customized, large-scale virtual environments that would be much costlier and prohibitively time-intensive to construct as ‘brick and mortar’ representations has paved the way for study that would not have been otherwise viable (Foreman, et al, 2000). As such, for more than two decades, researchers have been exploring the validity of learning spatial navigation in virtual environments. Along the way, some important findings have emerged with regard to the transferability of virtual learning to the real world. For example, researchers have demonstrated that navigating a virtual environment requires very similar cognitive abilities to those utilized when completing the same activity in the real world (Allahyar & Hunt, 2003). Although Perani, et al. (2001) identified substantial differentiation between learning in real worlds or virtual environments, they also found that numerous areas of the brain were activated in similar fashion during engagement in both genres. For example, the authors found that brain activation for functions such as object/hand actions, motion processing, visuospatial planning, motor and spatial orientation, and attention and perception of actions (along with intent, monitoring, and evaluation of action plans) were activated both while viewing events in the real world, and when using a virtual environment (Perani, et al., 2001). These conclusions support the findings of Richardson, et al. (1999), who concluded that similar cognitive processes are involved in both virtual and real-world spatial navigation. The authors first introduced undergraduate students to a virtual layout of a building, and then studied their ability to transfer their acquired understanding of the virtual building's spatial layout to its real-world counterpart. They found that, although learning multi-floor navigation was less effective, participants' ability to navigate a single-floor virtual representation of a building was predictive of their ability to navigate the same floor in a real-world building (Richardson, et al., 1999).

When studying the efficacy of learning to navigate within a real-world Kiel locomotor maze versus a performing the equivalent learning activity within a virtual representation of the same maze, Foreman, et al., (2000), found that participants who navigated the virtual rendition of the maze evidenced an "almost perfect transfer" (p. 57) of the target spatial information from the virtual environment to the real one. In their study of the variables that impacted the transfer of spatial learning in a virtual maze to a real-world demonstration of acquired skill, Waller, et al. (1998) concluded that, not only was spatial learning in a virtual environment transferable to real-life application of the newly-acquired knowledge and skills, but virtual environment training was able to surpass the results of its real-world counterpart when done often enough (Waller, et al., 1998).

The Study of Behavior in Virtual Environments

A number of studies have measured demonstrated behavior during a task in a virtual environment. For example, Latu, et al. (2013) looked at the behavior of individuals who were exposed to positive role models during a virtual public speaking activity. The authors identified a meaning (empowerment) attached to a certain behavior (length of time spent speaking) and from that coupling, decided to quantify the speaking time of participants (Latu, et al., 2013). The authors video-recorded participants during their delivery of a speech in front of an audience of avatars within a virtual environment, after which the authors noted each participant's speaking time and compared the number of seconds that each participant spoke to their self-rated performance, and to an external evaluation of the quality of their speech delivery (Latu, et al., 2013).

Several studies have focused on analyzing verbal behavior (conversation) within a virtual environment. Heller and Procter (2014, in Wu, et al., 2015) analyzed conversations between participants and a computer that took place both in, and outside of, a virtual environment. Kramer, Oh, and Fussell (2006, in Wu, et al., 2015) found significant differences between participant conversations held via four diverse mediums, but all used within a virtual environment. Wu, et al. (2015) studied the impact of a virtual environment's spatial cues on the verbal behavior of participants. Focusing on text-based communication, the authors analyzed the nature of the communication between the participants in their study and looked at changes related to the 'physical' layout of the virtual environment.

Taking a different approach to investigating the impact of 'physical' characteristics on participant behavior, Lam and Riedl (2011) looked at the relationship between the appearance of an avatar, and the behavior of the participant who was controlling that avatar during a role-playing game. The authors found that participants would modify their avatar's behavior (and therefore, their own) during the game in order to 'match' an avatar's behavior with its appearance (Lam & Riedl, 2011).

To study a different aspect of student behavior, Marques and Belo (2011) investigated post-secondary students' use of learning tools on web-based learning platforms. The authors identified three profiles with respect to the frequency and type of learning platform usage in which students were engaging: those whose profile was characterized by visiting the website only to view course and task information; a second group whose profile was characterized by visiting the site to view course and task information but also viewed information contributed by other students on the site; and a third group whose profile was characterized by the addition of participation in online discussion in addition to completion of the activities in which the other students were engaged. Along similar lines, Toprakci (2007) focused on developing student profiles based on internet usage for both personal and educational purposes. Variables involving students' stated purposes for using the internet, usage times and locations, and other related information were analyzed by the author, who found that less than 50% of students used the internet for educational purposes (Toprakci, 2007).

Behavioral Microanalysis.

Behavioral microanalysis is a study format which utilizes a combination of both qualitative and quantitative research methods to identify “minimal changes” (Ullsten, Eriksson, Klassbo, & Volgsten, 2017, p. 147) in behavior. For example, behavioral microanalysis has been utilized extensively in developmental psychology for the study of “moment-to-moment” (Ullsten, et al., 2017, p. 147) interactions between parents and children.

Burgio, et. al. (1992) used behavioral microanalysis to examine the behavior of psychogeriatric inpatients who were randomly assigned to two different drug therapies. The authors generated an hourly log of the frequency of target behaviors (aggression, agitation, vocalization, paranoid verbalization, and noncompliance), along with an intense observation and recording of participant behavior during two 10-minute intervals per day for an average of 11.4 days. The authors concluded that the use of behavioral microanalysis provided a “practical methodology for teasing out specific effects” (Burgio, et al., 1992, p. 261).

With the advent of technology has arisen the potential to study behavior at a much higher level of complexity and precision (Cotter, et al., 1998). One such example of the use of technology to facilitate an in-depth investigation of behavior was conducted by Cotter, et al. (1998), who used video-recording to capture the interactions between caregivers and adult care recipients during two learning tasks. The authors identified the following target interactive behaviors: verbal behavior for both caregiver and recipient, touching of test materials for both caregiver and recipient, caregiver physical assistance toward (or touching of) recipient, and baby talk (Cotter, et al., 1998). The authors conducted a behavioral microanalysis during which the video-recordings were analyzed in detail. The frequency of target behaviors was assessed by using a computer-assisted data collection system which generated a data stream for each participant during specified time blocks (Cotter, et al., 1998). Each video was closely viewed six times – each time for the purpose of isolating one particular behavior – while the observer tabulated occurrences by clicking a computer key that increased the associated tally (Cotter, et al., 1998). The authors concluded that the caregivers of younger adult care recipients incurred a higher incidence of positive statements and modeling/gestural prompts than the caregivers of older adult recipients, while the opposite was true with regard to incidences of physical assistance and task-assumption (Cotter, et al., 1998).

More recently, Sikt, Bavelas, and de Jong (2013) conducted a “rigorous moment-by-moment” (p. 36) behavioral microanalysis of therapist-client dialogues. During two 6.5-minute sessions each of solution-focused therapy and cognitive behavioral therapy, and one 10-minute session of motivational interviewing, the authors digitally video-recorded face-to-face dialogues between therapists and clients. Through the use of “repeated, frame-by-frame viewing” (Sikt, et al., 2013, p. 36), the authors tabulated instances where the therapist formulated (e.g. summarized or paraphrased) the client’s own words. Results of the analysis revealed that during formulation, the solution-focused therapists preserved twice as many of their clients’ original words and added the fewest of their own, while the reverse was true for the motivational interviewer, who added more than thrice the number of his own words when compared to the solution-focused therapists (Sikt, et al., 2013).

In yet a more recent study, Ullsten, et al. (2017) conducted a case study of the use of lullaby singing as a non-pharmaceutical pain mediator for infants during medical procedures. Two premature infants were video-recorded during necessary painful medical procedures that each infant underwent twice: once while receiving a typical approach to care, and once during which a standardized singing of a lullaby was simultaneously proffered (Ullsten, et al., 2017).

Physiological data (e.g. heartrate, blood pressure, blood oxygen) was collected at 10-second intervals by a computer connected to the standard bio-monitors, while five target facial actions and two target hand actions – all seven of which were associated with an infant experiencing pain – were hand-coded and subjected to second-by-second microanalysis of the video-recording of the two infants (Ullsten, et al., 2017). Results of the study showed that both the physiological and behavioral responses of the infants were more stable during the lullaby condition than when the infants were offered standard care only (Ullsten et al., 2017).

The Current Study

Virtual environments are a useful pedagogical tool for the facilitation of active, intrinsically motivational learning opportunities for students. As a result, they are being increasingly investigated for their potential as a platform for innovative education delivery (US Department of Education, 2010, in Kopcha, et al., 2016) because they can deliver many of the benefits of traditional educational approaches, while promoting greater engagement with educational concepts.

A range of prior studies have endeavored to create targeted profiles of students in various types of learning situations. However, there is a dearth of studies identifying profiles amongst participants who are engaged in education-oriented learning tasks within a virtual environment. Therefore, the current study will explore the characteristics – various aspects of computer usage and spatial navigation – of students currently enrolled in a post-secondary institution in western Canada. The identified characteristics will be used to develop student profiles amongst undergraduates who engaged in a computer-delivered learning task in one of three different spatial conditions of a virtual environment which is not dissimilar in nature to those often used by students outside of the classroom, on their own time.

A virtual environment can essentially act as a highly customizable laboratory for research purposes, for researchers have established that it is possible to use a virtual environment as an ecologically-sound venue within which to study the behavior of individuals (Loomis, et al., 1999, Williams, et al., 2007). However, the manner in which individuals conduct themselves with a virtual environment will have a direct impact on the nature and type of benefit that they are able to reap from their engagement within it. As such, one aspect of this study is to explore how the spatial configuration of a virtual environment may play a role in the behavior of participants.

Some studies have used the technique of video-recording participants (Jurik, et al., 2014), and some have done so during participants' activities within a virtual environment (Garrido-Inigo & Rodriguez-Moreno, 2015). However, there is a noticeable lack of studies that have analyzed such video-recordings on a microsecond basis in order to examine behavioral nuances during an informational task. In the current study, the behavior of a subsample of participants will be video-recorded and a behavioral microanalysis will be conducted according to a precise protocol. Behavioral microanalysis will facilitate an in-depth exploration of learner response – as expressed through behavior – to an information-based task in spatially-diverse virtual environments. A case study format will then be implemented to explore the diverse array of research opportunities afforded by the multiple combinations of spatial condition, along with student profile membership, and participants' behavioral patterns.

In summary, the current study intends to conduct a multi-stage research process that will explore students' experiences during an information-based task within spatially-diverse virtual environments. Although this study will utilize both quantitative and qualitative research procedures, it is not considered to be a mixed method research design as it does not utilize one research paradigm as a method of complementing the other or seeking to create overlap in order to avoid experiencing gaps as a result of the inherent limitations of either method. Rather, the current research process will begin by using quantitative research methods to conduct a broad exploration and analysis of specific characteristics amongst the entire sample of 133 student participants. Following the quantitative analysis, the study will focus on taking what has already been learned and conducting a behavioral microanalysis that will concentrate on the development of a deep understanding of students' experiences in the virtual environments by conducting multiple qualitative case studies on the nine-participant subsample. Although participant interviews will not be conducted, the case studies will utilize information gathered from the other three categories most often used in qualitative data collection: observation, documents, and audiovisual materials (Creswell, 2015).

Method

Participants

Prior to commencing recruitment of participants, ethics approval was granted by the Research Ethics Board (REB2) of the University of Alberta, which reviews all research designs involving training interventions for educational purposes. All REB2 standards were adhered to during implementation of this study. Participation in this study was voluntary. Participants were free to withdraw at any time prior to (or during completion of) the study tasks and, up to the point of dissemination, were given the option to request removal of their data from the data set.

The participants for this study were a convenient sample of 138 third- and fourth-year undergraduate students at the University of Alberta who were enrolled in the Winter, 2017, term for the educational psychology courses EDPY 302 and EDPY 442. Professors of these two courses agreed to grant up to 5% of students' course mark (2 credit hours) for completion of a research component. Students had the option of completing the research component by participating in a single two-credit study or two single-credit studies. Alternatively, students could choose to complete the requirement by submitting a research assignment stipulated by the department. Students were awarded one credit hour for their participation in the current study.

Students signed up to participate in their study of choice by using the Department of Educational Psychology's online Research Participation System (known as SONA). Normal (or corrected to normal) vision was the only eligibility requirement listed on SONA as a requirement for participation in this study. Approximately two dozen time slots – each with 16 available spots – were made available to participants, from which each chose the timeslot most convenient for him or herself. To prevent pre-selection of participants as a result of interest (or lack thereof) in virtual environments, the study was listed in the online system only by its approval code.

Four of the 138 participants participated in the linear condition as a test of the virtual environment's function. No premeasures were administered to these four participants and no data was collected on their participation. An additional participant filled out the premeasures and completed the information-based task within the clustered condition, but the data from this participant was lost during technical transition and was not recoverable. The remaining participants completed all of the premeasures and the virtual environment tasks, resulting in collection of 133 full sets of data.

Materials

Measures. Three premeasures were administered to the participants. Gilster (1997, in Boechler, Dragon, & Wasniewski, 2015) coined the term *digital literacy* and defined it as having the "skills to operate technology" (p. 4). As one objective of this study was to examine participant behavior in a computer-delivered virtual environment, the *Computer Experience*

Questionnaire (CEQ) measure of digital literacy (Boechler, et al., 2015) was used to capture participants' familiarity and competency with various elements of computer use. The CEQ is a self-report questionnaire composed of three separate measures of computer experience: *Video Game Experience* (VGE), *Social Media Experience* (SME), and the *Software Recognition Test* (SRT). Participants in the current study completed all three facets of the Computer Experience Questionnaire on the computer. Both video game experience and social media experience were measured utilizing a forced-choice format in which participants selected from five frequency descriptions (see *Methods* section, *Statistical Analysis* subsection) to identify how often they used the specified media during four periods of their lifetime: elementary school, junior high, high school, and "in recent weeks". The measures of video game and social media experience were developed from a previous version of the Computer Experience Questionnaire, which utilized a measure called the Recreational Experience Scale to assess the frequency of both constructs in order to establish respondents' familiarity with computer usage (Boechler, et al., 2015).

The Software Recognition Test is based on the Author Recognition Test (Stanovich & Cunningham, 1992, in Boechler, et al, 2015) which assesses exposure to print materials. In similar fashion, the Software Recognition Test measures exposure to different applications of computer and/or online software (Boechler, et al., 2015). Preliminary research by the authors of the SRT has indicated the promise of predictive validity for educational purposes (Boechler, et al., 2015). During completion of the Software Recognition Test, the respondent is presented with a list of 40 software titles and instructed to identify the titles that they recognize. The list is composed of 20 titles of valid software programs and 20 titles of programs which do not exist, and there is no limit to the number of selections that a participant is allowed to make. The SRT is scored in a right-minus-wrong fashion, thus allowing scores to range from a maximum score of 20 down to a minimum score of -20.

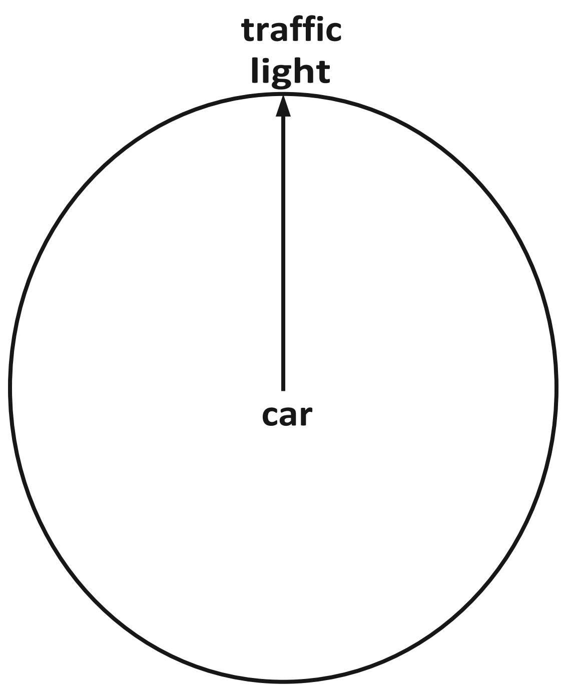
One objective of this study was to assess participant behavior with regard to navigation of different spatial environments, so the second premeasure administered to participants was the Spatial Orientation Test (SOT). Spatial orientation is defined as “the ability to imagine how a stimulus array will appear from another perspective” (Kozhevnikov & Hegarty, 2001, p. 746). The SOT has demonstrated reliability and validity with regard to assessing spatial orientation, along with strong correlations to both “sense of direction” self-reports and large-scale spatial cognition tasks, such as route planning (Hegarty & Waller, 2004).

The Spatial Orientation Test is a timed pen-and-paper task that proffers a single question on each of twelve pages. A constellation of seven objects is displayed on the top half of each page, while a circle on the bottom half of the page has one object’s name printed in the center (the *station point*), along with an arrow pointing upwards from the circle’s center toward the printed name of a second object (Hegarty & Waller, 2004). See Figure 1 for a sample item from the Spatial Orientation Test.

Williams, et al. (2007) explained that individuals have the ability to create a personal representation of an unfamiliar perspective when it is located within a relatively familiar context. The Spatial Orientation Test taps this capacity by repeating the same contextual layout for all twelve items in the test. Respondents are asked to imagine being at the station point and facing the second object, whereupon they are asked to indicate the direction of a third object (the *target*) by drawing a second arrow from the center of the circle to where the respondent believes the target object would be (Hegarty & Waller, 2004). Each imagined perspective change required a

Figure 1. Sample Item from Spatial Orientation Test (Hegarty & Waller, 2004)

1. Imagine you are standing at the **car** and facing the **traffic light**. Point to the **stop sign**.



shift of at least 90 degrees, and participants were asked not to alter the orientation of the test booklet's straight position on the desk (Hegarty & Waller, 2004).

The instructions to the respondent read "Imagine you are at the [station point] and facing the [second object]. Point to the [target]." (Hegarty & Waller, 2004, p. 178). Participants were also asked to refrain from writing or making any marks on the constellation of objects at the top of each page. The Spatial Orientation Test stipulated a five-minute time limitation, after which no further items were allowed to be attempted. Items were scored on a binary right-wrong basis that was determined by whether the written response was within the same quadrant (0-90 degrees, 90-180 degrees, 180-270 degrees, or 270-360 degrees) as the correct answer (Kozhevnikov & Hegarty, 2001). The Spatial Orientation Test was used in the current study to provide a measure of the participants' demonstrated spatial skill (DSS).

The third premeasure used in the current study was the 15-item *Santa Barbara Sense of Direction Questionnaire* (SBSOD), a self-report measure in which participants score their own directional skills to provide a measure of perceived spatial skill (PSS) (Hegarty, et al., 2002, Turano, et al., 2009). Each statement was self-rated by the participant using a 7-point Likert scale, with a score of "1" indicating "Strongly Agree", a score of "4" indicating "Neither agree nor disagree", and a score of "7" denoting "Strongly Disagree". To avoid the problem of response set, seven of the questions represented competence – e.g. "I am very good at reading maps" – while the remaining eight questions denoted a lack of skill (e.g. "I don't have a very good "mental map" of my environment"). Initially comprised of 27 items, the SBSOD was reduced to the current 15 items (see Table 1) after these items were determined by factor analysis to be closely associated with the statement "My sense of direction is very good" (Hegarty, et al., 2002). Internal consistency amongst the 15 items on the SBSOD has been analyzed at 0.88, and test-retest reliability with a 40-day interim period has been analyzed at 0.91 (Hegarty, et al., 2002, p. 430).

A post-test composed of ten multiple choice questions related to retention of the historical information presented on the boards was also administered to participants in the current study. Though not applicable to the current study, participant scores on the multiple-choice post-test were gathered as data for use in future research.

Virtual Environments. Three custom-designed virtual environments were created by an experienced technology team from the Technology in Education department within the faculty of Educational Psychology at the University of Alberta. The virtual environment development team utilized version 4.14 of the "ubiquitous" (Gaudiosi, 2009, p. 24) Epic Games *Unreal Engine* development platform to create the customized virtual environments. Unreal Engine supports game development "at any level" (Pachoulakis & Pontikakis, 2015, p. 5), thereby appealing to professional and independent game designers alike (Pachoulakis & Pontikakis, 2015). The development platform offers reusable code in addition to object-oriented programming, making it possible for developers to focus largely on game concepts and less on technical challenges (Torres-Ferreyros, Festini-Wendorff, & Shiguihara-Juarez, 2016). These features allow Unreal Engine to be both budget- (Torres-Ferreyros, et al., 2016) and user-friendly while also consistently delivering end-products of exceptional quality (Gaudiosi, 2009, Torres-Ferreyros, et al., 2016), making it ideal for the development of the customized virtual environments that were used to conduct the current study.

The virtual environments for this study were designed to allow for time-stamped, second-by-second tracking of each avatar's individual movements within the virtual environment. Two separate detailed logs of digital data were automatically generated for each avatar: an *event log*

Table 1. Santa Barbara Sense of Direction Scale

Item	Question (Note: Italicized items are reverse-coded when scoring)
1	I am very good at giving directions
2	*I have a poor memory for where I left things
3	I am very good at judging distances
4	My “sense of direction” is very good
5	I tend to think of my environment in terms of cardinal directions (N, S, E, W)
6	*I very easily get lost in a new city
7	I enjoy reading maps
8	*I have trouble understanding directions
9	I am very good at reading maps
10	*I don’t remember routes very well while riding as a passenger in a car
11	*I don’t enjoy giving directions
12	*It’s not important to me to know where I am
13	*I usually let someone else do the navigational planning for long trips
14	I can usually remember a new route after I have travelled it only once
15	*I don’t have a very good “mental map” of my environment

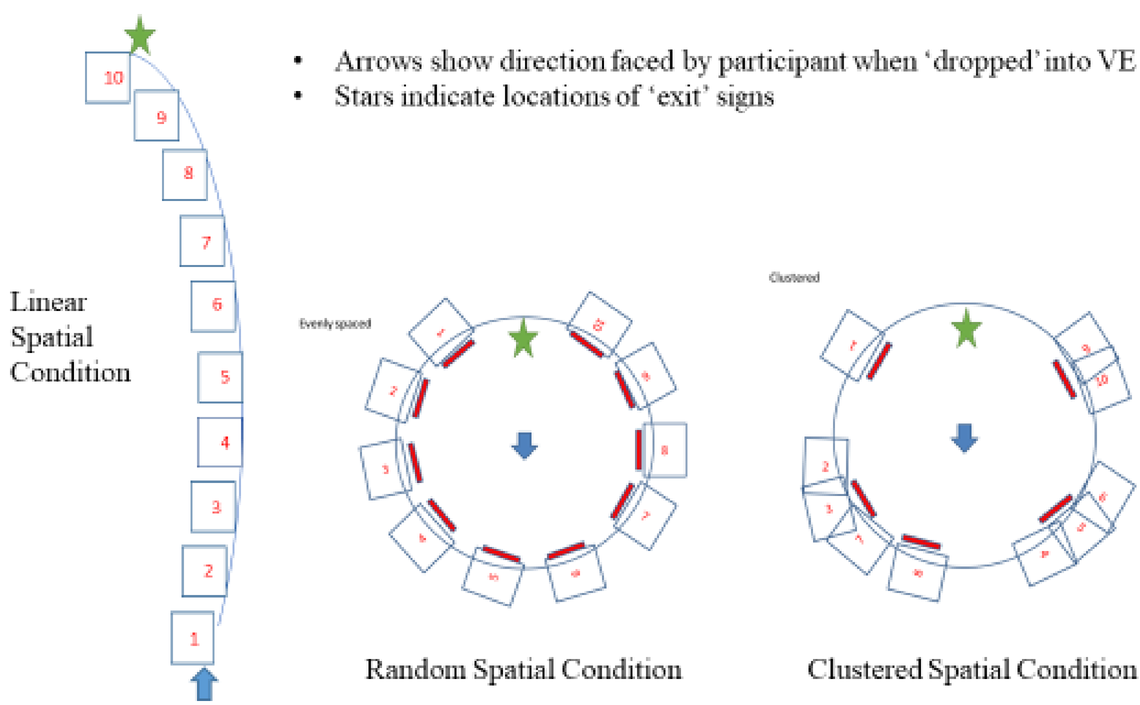
that detailed the time-stamp of an avatar’s entry into, or exit from, one of the *stations* (see below for a detailed description of the structure and function of a station), and a *coordinate log* that recorded the x, y, and z coordinates of the avatar once per second. Although the nature of the electronically-generated data was determined to be incompatible with the specific data collection needs of this study, together the two digital logs will allow participant movement within the virtual environment to be electronically recreated and analyzed during future study.

Each virtual environment was designed with the same general décor: a museum with a very understated interior. However, the virtual environments differed noticeably from each other with regard to spatial layout, thereby forming three distinct spatial conditions. Within the museum, ten alcoves – termed *stations* – were created. In the first spatial condition – termed the *Linear Condition* – the ten stations were arranged in sequential order beginning with station one and finishing with station ten. Each station branched off from the left side of a single hallway that curved slightly to the left, preventing participants from seeing the end point of the hall until reaching the tenth station. At the end of the hallway, a sign facing the participant provided instructions on how to exit the museum (see Figure 2 for a visual representation of the *Linear Condition*).

The second spatial condition – termed the *Random Condition* – featured a circular foyer around which the ten stations were arranged in sequential order. The stations were arranged from number one to number ten if navigating counter-clockwise around the foyer, or from ten to one if navigating clockwise. A sign on the wall between the entries to the first and tenth stations provided instructions on how to exit the museum. The interior of each station was blocked from view by a freestanding blank wall – facing the foyer and placed just inside the entrance to the station – with space on either side through which the station could be entered (see Figure 2 for a visual representation of the *Random Condition*).

The third spatial condition – termed the *Clustered Condition* – also featured a circular foyer around which the stations were arranged, with an exit instruction sign on the wall between two of the alcove entries. However, in this case, the stations were grouped into five clusters of one, two, or three stations within a single alcove. The clusters – sequentially numbered using Roman numerals I through V for reference purposes – were arranged counter-clockwise around the foyer with the ‘exit sign’ located on the wall between the entrances to Cluster I and Cluster V. Cluster I was a *single cluster* containing only station one. Cluster II was a *triple cluster* holding stations seven, three, and two, which appeared left to right in that order upon entry to the cluster. Cluster III was a single cluster containing station eight, while cluster IV was a triple cluster encompassing stations six, five, and four (appearing left to right). Cluster V was the only *dual cluster*, enclosing stations nine to the left, and ten to the right. Like the random condition, visibility of the cluster interiors from the foyer was blocked by freestanding blank walls located within the cluster entrances (see Figure 2 for a visual representation of the *Clustered Condition*).

Figure 2. Three Spatially-Diverse Virtual Environments



Four free-standing display boards were placed within each of the ten stations, for a total of forty displays. The first two boards in each station were designated as 'A' and 'B' and were joined together side-by-side, with board A located to the left of board B. The center joint angled outward like the exterior of an open book, causing the two boards (now assuming the positions of front and back book covers) to rest at an angle from each other in slightly different forward-facing directions. The second set of boards were designated as 'C' and 'D', joined in the same fashion as above, and placed to the right of the A/B boards in a manner that suggested a traditional English language left-to-right reading sequence from board A through to board D (see Figures 3 and 4 for visual representations of the board layouts for Station One and Station Ten, respectively).

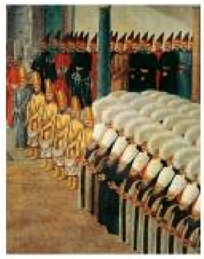
Kobayashi (1996, in Rieber, Tzeng, & Tribble, 2004) found that dually coded information was more salient than information presented through only one medium, as dually coded information offered twice the retention opportunity to learners. Although it was not the purpose of the current study to assess learning outcomes related to information retention, it was nevertheless important to promote and preserve the opportunity for future research to do so. As such, information on the forty information boards was presented using a dual-encoding system (Rieber, et al., 2004) that provided verbal information through written text displayed on the lower section of each boards, along with visual information presented through corresponding pictures that were displayed immediately above the text. Concurrent with the 'museum' theme, the text and pictorial information presented were of a historical nature.

Technical Materials. All of the research trials used Apple Macintosh laptops provided by the Research Innovation Space in Education (RISE) laboratory at the University of Alberta, where the trials were conducted. For each trial, the number of prepared computers matched the

Figure 3. Station One: Information Boards A, B, C, D

The Ottoman Empire lasted from the late 13th century to 1923. The Ottoman Empire territories were determined by the military power of the dynasty at any particular time.

With Constantinople as its capital and control of lands around the Mediterranean basin, the Ottoman Empire was at the centre of interactions between the Eastern and Western worlds for six centuries.



The **Janissaries** ("new soldier") were elite military units that formed the Ottoman Sultan's household troops and bodyguards.

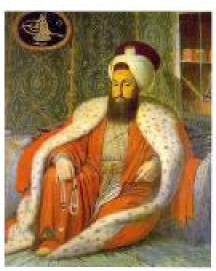
The Ottomans were one of the first in Europe to have this type of standing, well-trained army.

The corps was most likely established during the reign of Murad I (1362–89).

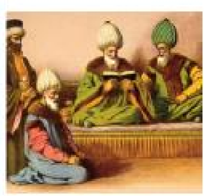
They began as an elite corps of slaves made up of conscripted young Christian boys. They became famed for internal cohesion cemented by strict discipline and order.

The Janissary became members of the *askeri* class, the first-class citizens or military class. Unlike typical slaves, they were paid regular salaries. Forbidden to marry or engage in trade, their complete loyalty to the Sultan was expected.

Figure 4. Station Ten: Information Boards A, B, C, D



Over time, the corps gained immense power to the point that they controlled the military and political scene of the Ottoman state. In the late 1700's and early 1800's, Selim III ruled as Sultan. He attempted to create military reforms to modernize the Ottoman armies.



Selim's reorganizations and the increasing influence of France evoked a strong reaction from the Janissaries, the ulama (men of religious learning), and others adversely affected by the reforms. The ulama had no formal legislative role, and so their power was exercised through influence over public opinion and acceptance (or not) of a ruler.

In 1805, the Janissaries mutinied in Edirne (in Thracian Turkey) and were joined by the ayan (local notables), who had previously supported the sultan. The Janissaries led an uprising that overcame the new army and marched on Istanbul. The city was stormed and Selim III removed from power by the Janissaries.

In 1826, Sultan Mahmud II declared war on the Janissary rebels and, on their refusal to surrender, had cannon fire directed on their barracks. Most of the Janissaries were killed, and those who were taken prisoner were executed. This became known as "The Auspicious Event".

number of expected participants, with the addition of at least one spare computer that could be calibrated to the virtual environment condition of any computer that malfunctioned and needed to be replaced during the trial. During trials, the laptops were positioned individually on desks that were placed around the laboratory with approximately equal space between them. In between trials, the laptops were returned to their charging stations to ensure that a sufficient amount of battery power was available for each trial. During the information task, participants navigated their avatars within the virtual environment by pressing the four arrow keys (up, down, left, right) on the built-in keyboards of the Apple Macintosh laptops. Identical ballpoint pens were provided to participants for completion of the pen-and-paper spatial test, securing uniformity of administration and reducing variability by ensuring that participants did not provide any of the materials used in the trial.

Identification codes were electronically generated, and a unique code was randomly assigned to each computer station for each trial. Participants were asked to write the identification code on the cover of their paper-and-pen task. At the conclusion of each trial, but prior to amalgamating the data collected during the trial, researchers verified each code as matching its electronic version. At the conclusion of each trial, data was uploaded from the computers directly to a password-protected Google Drive associated with the Technology and Learning Sciences (TALS) lab at the University of Alberta.

Recording of computer screen activity was accomplished using the *Screencast-0-Matic* software (www.screeencast-o-matic.com). Access to the recordings was restricted by upgrading the screencast-o-matic software to a *pro-account* status in order to gain the ability to turn off cloud storage so that videos could be stored locally. The recording software was set up on each designated computer by the researcher just prior to the research trial and activated by the participant when ready to commence the computer tasks that were targeted for video-recording.

Procedure

Participant recruitment. A convenient sample of 138 undergraduate university students was recruited for this study. Participation was voluntary, and participants were free to withdraw their participation at any time. Identification of students was necessary for the purpose of granting course credit to students, after which all research data from this study was retained only under anonymous identification codes. To assist in preventing pre-selection of participants as a result of interest (or lack thereof) in virtual environments, the study was listed in the online system only by its approval code, thereby restricting participants' *a priori* access to information regarding the title and nature of the study.

Random assignment. A total of 28 individual research trials encompassing 412 timeslots were made available to participants on the SONA online system, from which each participant chose a single timeslot. The high ratio of timeslot options to participants ensured that researchers were not directing specific participants toward a particular research trial or spatial condition. Some of the research trials ran only one virtual environment condition, some ran two, and some trials ran all three conditions. All research trials took place in the RISE laboratory, and random assignment was further ensured through the advance delegation of a pre-determined number of computers to run each virtual environment condition, but no directed assignment of participants to a particular machine during the trial. Instead, upon arrival, participants were asked to "choose any desk with a computer on it".

Participants were unaware that the first research trial was designated as a test of the effectiveness of the virtual environment's function, and that they would not complete any of the measures or have data from their participation in the virtual environment collected. Four participants signed up for the test trial and participated in the virtual environment tasks in the linear condition. Of the 134 remaining participants, 44 were randomly assigned to the linear condition, 45 to the random condition, and 45 to the clustered condition.

Protocol. The virtual environment application was locally stored and operated from an internal server. Access to the virtual environment was password protected, requiring the researcher to set up the virtual environment and computer-delivered premeasures on each computer work station just prior to the commencement of a research session.

It took approximately 40 – 60 minutes to complete each research trial. In order to be granted course credit for their participation, students signed in upon entering the RISE laboratory. After choosing their station, participants were asked to wait for the researcher to give instructions before touching or doing anything. A whiteboard message at the front of the room repeated the request for participants not to touch anything until asked to do so. A scripted protocol was then read. The protocol began with the instruction for participants to read the untitled consent form provided at each desk, sign and return one copy if they wished to proceed with the trial, and retain the other copy for personal reference. The researcher collected the signed consent forms, compared the forms with students' signatures on the sign-in sheet, and entered the students' names into the SONA system to confer course credits.

The next instruction on the protocol script described the pen-and-paper spatial task, beginning with a sample item. When all participants had reviewed the task instructions and the sample item, they indicated their readiness to begin the task by turning to a page within the test that read "STOP". Two rules for completion of the spatial test were then emphasized: not rotating the paper, and not drawing on the layout of icons at the top of each page. The five-minute period for the task was then commenced, after which participants were asked to stop working, turn their papers upside down, and set them aside on their desk until later.

Following completion of the paper task, participants were asked to wake up the laptop computers and double-click on the icon for Unreal Engine. From that point forward, further task instructions were delivered via text provided on the computer. Once the Unreal Engine icon was activated, the virtual environment task was next to occur. The following set of instructions were displayed on a message board within the virtual environment: “Welcome. To move your avatar, use the arrow keys on the lower right corner of your keyboard. Practice moving your avatar until you are comfortable with it. When you are ready to continue with the task, click on the green button on the far wall in front of you.” After clicking on the green button, the following message instructed participants: “In the next task, you will be presented with a number of museum displays. Please read all material very carefully and try to remember as much as you can. When you are ready to begin, approach the green button and press “Enter” on your keyboard.” Pressing *enter* ‘teleported’ the participant’s avatar into the museum, where they began the task of navigating the virtual environment and interacting with the historical information on the boards.

At the end of the virtual environment task, another set of instructions appeared, the nature of which depended on the spatial condition that the participant had just finished navigating. For the linear condition, the message read: “When you have finished viewing all of the displays, return to this location, walk up to the red button, and press “Enter” on your keyboard to go on to the next task.” For the random and clustered conditions, however, the instructions read: “When you have finished viewing all of the displays, walk up to the green button and press “Enter” on your keyboard to go on to the next task.” Pressing *enter* took the participant to a linked webpage, which displayed the instruction to write a displayed identification code on their paper spatial task. The webpage also contained the multiple-choice post-test, followed by the Computer Experience Questionnaire, and the Santa Barbara Sense of Direction Scale.

The need for replacement of a malfunctioning computer occurred twice throughout the entire sequence of trials, both times during a point in the task sequence that allowed replacement of the computer without interrupting any of the tasks, themselves. All of the tasks that participants competed on the computer were completed at the preferred pace of the participant. Upon completion of the final task, the following message appeared: "You have now completed all tasks. Thank you for participating. You are free to leave." Once they had completed all tasks, participants were asked to leave the computer open and 'as is' on the desk, alongside the paper copy of the Spatial Orientation Test and the pen. A titled debrief sheet explaining the purpose of the study was provided to each participant as they were leaving the RISE laboratory.

After all participants had completed the tasks and exited the RISE laboratory, the researcher went to each of the desks used by a participant, verified that the identification code written on the paper task matched the code displayed on the computer file, and uploaded the participant's file to the Google Drive. The computers were then returned to the charging station until the next trial.

Video-recording of subsample. A single research trial for which exactly nine participants had registered was selected as a convenient subset of the research sample. For this trial, three computers were assigned to each of the three virtual environment conditions, and video-recording software was downloaded on all nine machines, plus one spare machine. Upon entry to the RISE laboratory, each participant chose their own computer station as per above protocol. Participants were informed that their on-screen activities would be video-recorded and they were asked to activate the Screencast-O-Matic recording software just prior to double-clicking on the Unreal Icon. The pre- and post-measure data for the subset of participants was collected according to the same protocol as that for the overall sample.

Statistical Analysis

Coding of responses. On the measures of video game and social media experience, forced-choice responses were provided by the participant in the form of frequency descriptions. These frequency descriptions were coded from 0 – 4 to convert them from string (worded) values to numerical values. Responses of “None” were coded as a zero, “1-3 hours” were coded as a one, “4-6 hours” were coded as a two, “7-10 hours” were coded as a three, and “More than 10 [hours]” were coded as a four.

Calculation of raw scores. The Spatial Orientation Test consisted of 12 items which were marked on a binary (right/wrong) basis. Raw scores were calculated by summing the number of items that were answered correctly. The minimum achievable score on the Spatial Orientation Test was zero, while the maximum achievable score was twelve. The raw scores for the measures of video game and social media experience were calculated by summing the coded values (0 through 4) from each of the four items. The minimum achievable score for both video game and social media experience was zero, while the maximum achievable score for each of the measures was sixteen.

Each item on the Software Recognition Test was worth one additive point if the answer was correct (e.g. the software in question was legitimate), or one detractive point if the answer was incorrect (e.g. the named software did not exist). The raw score for the Software Recognition Test was calculated by summing the additive points, and then subtracting the detractive points. The minimum achievable score (e.g. the participant selected all nonexistent software items and selected no legitimate software items) was -20, and the maximum achievable score (e.g. the participant only selected all of the legitimate items) was 20.

The 15 items on the Santa Barbara Sense of Direction Scale each featured a 7-point Likert scale which participants used to indicate their agreement with questions that denoted either the presence or the lack of a described spatial skill. To ensure that higher values on the Likert scale were consistently indicative of higher self-estimation of spatial skills, scores for 'positive' questions that denoted the presence of a skill (e.g. "My "sense of direction" is very good") were retained in their original form, while scores for 'negative' questions that denoted a lack of skill (e.g. "I have a poor memory for where I left things") were inverted. A score of one was thus inverted to seven; a score of two inverted to six; a score of three inverted to five; a score of five inverted to three; a score of six inverted to two; and a score of seven inverted to one. Due to its stable presence in the center of the Likert scale, a score of four remained intact regardless of the nature of the associated question. The raw score for the Santa Barbara Sense of Direction Scale was then calculated by summing the original scores from the positive questions together with the inverted scores from the negative questions. The minimum achievable score for the SBSOD was 15, while the maximum achievable score was 105.

Standardization of raw scores. With the exception of the measures of video game and social media experience, each of the premeasures featured different scoring values, rendering the scoring results incomparable when expressed as raw scores. In order to understand how each score contributed to an understanding of the participant, standardization was required to give each score equal weight and to allow for valid comparison of one score with another. For this reason, each of the raw scores was converted to a percentage of the maximum achievable score for that measure. The calculations performed on the raw scores for the purpose of standardization are listed in Table 2.

Cluster Analysis. To investigate the question of whether the scores on the premeasures administered to the participants would reveal patterns of pre-existing characteristics, a cluster analysis was performed on the data to investigate whether distinct student profiles would emerge amongst the 133 participants. A cluster analysis is an exploratory statistical method that groups homogeneous cases or variables into classifications – termed *clusters* – based on their similarities to each other and/or their differences from members of other clusters, thereby revealing defined identities for each cluster (Everitt, et al., 2011, George & Mallery, 2012,

Table 2. Standardization of Scores

Measure	Maximum Score	Conversion Calculation
Spatial Orientation Test (SOT) Used as a measure of demonstrated spatial skill (DSS)	12	[Raw Score x 100] / 12
Video Game Experience (VGE)	16	[Raw Score x 100] / 16
Social Media Experience (SME)	16	[Raw Score x 100] / 16
Software Recognition Test (SRT)	20	[Raw Score x 100] / 20
Sense of Direction Questionnaire (SRT) Used as a measure of perceived spatial skill (PSS)	105	[Raw Score x 100] / 105

Murray & Hunfalvay, 2017, Primack, et al., 2012, Zahner, et al., 2017). George and Mallery (2012) put this concept into terms that are easily understood, describing cluster analysis as a “similarities-of-features procedure” (p. 283).

Cluster analysis has been used in a wide variety of disciplines, including market research (Roman & Maxim, 2017), psychiatry, archaeology, genetics, weather classification, and astronomy (Everitt, et al., 2011), along with social marketing, public health (Primack, et al., 2012), psychology (Anic & Toncic, 2013, Elwin, Schroder, Ek, Wallsten, & Kjellin, 2017, Kitazoe, Fujita, Izumoto, Terada, & Hatakenaka, 2017), sport physiology (Lanferdini, et al., 2016, Murray & Hunfalvay, 2017), economics (Forte & Santos, 2015), and education (Nielsen & Yezierski, 2016, Ng, Lin, & Wang, 2016, Roman & Maxim, 2017, Zahner, et al., 2017).

Lanferdini, et al. (2016) used cluster analysis to identify performance profiles amongst a sample of cyclists. Zahner, et al. (2017) used the same type of analysis to identify strategy profiles amongst students, while Elwin, et al., (2017) used cluster analysis to identify sensory profiles for individuals with autism. For the purposes of the current study, cluster analysis was used to group participants into categories in order to identify participant profiles based on characteristics identified by scores achieved on the premeasures.

There is a powerful element of art to the scientific process of cluster analysis, for the information revealed by each stage of the process plays an important role in determining how the next stage will unfold and the researcher must therefore make numerous decisions of inclusion, exclusion, and prioritization as the statistical analysis proceeds (Everitt, et al., 2011). For example, determining the number of clusters – a key component of interpreting the results of the analysis – is largely a judgement call by the researcher (George & Mallory, 2012, Roman & Maxim, 2017). It is for this reason that cluster analysis is considered to be an exploratory process, for Everitt, et al. (2011) state that “It is generally impossible *a priori* to anticipate what combination of variables, similarity measures and clustering techniques are likely to lead to interesting and informative classifications” (9.1 Introduction section, para. 1). As such, it is a challenging exercise to determine which variables are important when defining clusters.

The current study investigated the idea that, when combined with the ability to navigate spatial environments, participants’ experience with various forms of computer-delivered media would help to identify similarities and differences amongst the participant sample. Three premeasures were identified as a means of revealing information associated with these particular constructs, and these premeasures were administered to participants. It logically followed, then, to use participant’s scores on the premeasures as the variables that became the initial criteria for cluster formation. The scores for video game and social media experience, along with the Software Recognition Test, were drawn from the Computer Experience Questionnaire. The scores from the Santa Barbara Sense of Direction Scale were used as a measure of perceived spatial skill (PSS), while the scores from the Spatial Orientation Test were used as a measure of demonstrated spatial skill (DSS).

All statistical calculations were conducted using the *Statistical Package for the Social Sciences* (SPSS) software, version 23. The alpha level for the statistical calculations for this study was set at $p < .05$. Hierarchical clustering has been called the “backbone of cluster analysis” (Everitt, et al., 2011, 4.6 Summary section, para. 1), and agglomerative hierarchical clustering is the most commonly used hierarchical process (Everitt, et al., 2011). The agglomerative process starts with each case initially forming a cluster of one. Each of these clusters is then combined with the other clusters that are most similar to it, forming larger clusters (Forte & Santos, 2015). The process then repeats, each time fusing clusters together to create ever larger clusters until the maximum number of clusters has been reached (Everitt, et al., 2011, George & Mallery, 2012).

Squared Euclidean distance is performed by calculating the difference for each variable for each participant and then squaring the differences and summing them together (George & Mallery, 2012). Squared Euclidean distance is the most commonly used measurement process for the facilitation of hierarchical cluster analysis (Maroco, 2007, in Forte & Santos, 2015) and was the default measure suggested by SPSS. A review of relevant literature revealed that squared Euclidean distance is commonly chosen by researchers to determine the distance between each case and/or cluster when conducting agglomerative hierarchical cluster analyses (Elwin, et al., 2017, Lanferdini, et al., 2016, Murray & Hunfalvay, 2017, Nielsen & Yezierski, 2016, Ng, et al., 2016, Roman & Maxim, 2017). As such, the current study also used squared Euclidean distances to determine the distance between cases within the hierarchical cluster analyses.

The five variables were used to conduct an agglomerative hierarchical cluster analysis using SPSS. Although the SPSS default agglomerative hierarchical procedure is the *between group-linkage* procedure, a review of studies that focused on identifying groups within a population revealed that Ward's agglomerative hierarchical method – wherein groups are linked using the smallest possible sum of squares for each group to reduce the within-groups variation and maximize the between-groups variation (Murray & Hunfalvay, 2017, Nielsen & Yezierski, 2016) – was the most commonly used hierarchical method (Maholtra & Birks, 2006, in Roman & Maxim, 2017) and appeared to be preferred by researchers conducting procedures similar to those used in the current study (Elwin, et al., 2017, Lanferdini, et al., 2016, Murray & Hunfalvay, 2017, Nielsen & Yezierski, 2016, Ng, et al., 2016, Roman & Maxim, 2017).

Ward’s hierarchical method employs a process of linking groups by calculating the means values within each cluster, using them to assess the difference between each case and the cluster mean, summing the results, combining the two clusters that are the most similar, and then repeating the process until the designated number of clusters has been reached (Roman & Maxim, 2017). As such, a test case using agglomerative hierarchical cluster analysis was first performed using the hierarchical between group-linkage method, and then conducted a second time using Ward’s method for comparison. A high level of concurrence between the two methods was observed with regard to group membership, and a decision was made to conduct hierarchical analysis for this study using Ward’s method in order to maintain fidelity with other studies discussed in the literature.

As a number of other studies have found that between three and five clusters were optimal (Elwin, et al., 2017, Forte & Santos, 2015, Murray & Hunfalvay, 2017, Nielsen & Yezierski, 2016, Ng, et al., 2016, Roman & Maxim, 2017), the initial Ward’s cluster analysis for this study was conducted with a request to generate results showing three, four, and five clusters. Analysis of the accompanying icicle plot and dendogram identified that four clusters was the optimal number for identifying distinct student profiles amongst the participant sample. The dendrogram – a diagram that illustrates the progression of cluster fusions – was ‘cut’ at different levels of cluster formation by drawing a horizontal line across it (Forte & Santos, 2015). The line of *best cut* revealed large differences in the heights of the clusters, with noticeable height difference above the level of four clusters, coupled with a minimal height difference below the level of four clusters (Everitt, et al., 2011). However, one of the challenges with Ward’s method (as with all agglomerative hierarchical methods) is that once an individual case has been fused with another case or cluster, the fusion becomes immutable and cannot be undone even if at some point in the comparison process it would make sense for the case to move to another cluster (Everitt et al., 2011).

On the other hand, non-hierarchical cluster analysis methods, such as k-means algorithms, retain the ability to fluidly move cases between clusters as the analysis progresses. The k-means optimizes cluster formation by rearranging cluster boundaries and keeping the new clusters only if they are an improvement on the prior attempt, thus ensuring the best final 'fit' for each case (Everitt, et al., 2011). However, a major challenge associated with k-means analysis is that the number of clusters must be selected in advance by the researcher, requiring the researcher to have some sense of what the optimal number of clusters will be (Anic & Toncic, 2013). As such, it makes sense to conduct a hierarchical analysis first and use the results of that analysis to determine the number of clusters for the k-means analysis. For this reason, it was decided to follow up on the Ward's cluster analysis with a non-hierarchical k-means cluster analysis to confirm the number and nature of the clusters (Elwin, et al., 2017, Kitazoe, et al., 2017, Lanferdini, et al., 2016, Murray & Hunfalvay, 2017, Ng, et al., 2016). For the current study, the results of the non-hierarchical k-means analysis corroborated the clusters defined by Ward's hierarchical analysis.

A case summary was generated in SPSS following the Ward's analysis of the five variables. It showed that the mean scores on the Software Recognition Test measure of general computer exposure were within six percentage points of each other for all of the clusters – and within three percentage points of the population mean – rendering the Software Recognition Test scores essentially moot when it came to determining differences between the clusters. An ANOVA conducted as part of the K-Means analysis lent further credibility to this conclusion. Although the SRT ($p = .033$), VGE ($p < .01$), SME ($p < .01$), PSS ($p = .044$), and DSS ($p < .01$)

scores all achieved statistical significance at .05 when four clusters were created, an exploratory ANOVA conducted for comparative purposes determined that when cases were further consolidated by reducing the number of clusters to three, the Software Recognition Test scores ($p = .235$) dramatically lost their ability to distinguish between clusters. Given the recommendation that "Variables should only be included [in a cluster analysis] if there is good reason to think they will define the clusters. Irrelevant … variables should be excluded" (Everitt, et al., 2011, 9.2 Using Clustering Techniques in Practice section, para. 2), it was determined to exclude the Software Recognition Test scores and rerun the cluster analyses using only the other four variables.

Therefore, a new cluster analysis using Ward's method was conducted with the four remaining variables: video game experience and social media experience (which measure actual computer usage), perceived spatial skill (as measured by the SBSOD), and demonstrated spatial skill (as measure by the SOT). A range of three to five clusters was requested, and examination of the resulting icicle plot and dendogram again confirmed that the optimal number of clusters was four.

A follow-up k-means analysis was conducted and confirmed the existence of four distinct clusters. An eyeball case-by-case comparison was performed, cross-referencing the cluster memberships assigned by the Ward's analysis with the cluster memberships defined by the k-means algorithm. This comparison showed that the clusters remained largely cohesive across methods and that very little scatter was evidenced, with large portions of all four of the clusters remaining intact across methods. For example, of the 52 participants assigned to a particular cluster by Ward's method, 49 of them retained the same cluster membership when it was defined by the k-means algorithm.

In addition, as a part of the k-means analysis, an analysis of variance (ANOVA) was conducted on the four variables used to define the clusters. The results confirmed that all of the variables were statistically significant at .05 level of significance, indicating that each variable had an important impact on distinguishing between the groups. Elwin, et al. (2017) conducted a Tukey post hoc analysis to compare clusters; the same was done in this study to help identify the distance between cluster means for each variable. A discussion of the Tukey analysis for the current study can be found in the *Results* section of this study.

Table 3. Terms

Term	**Definition**
Board	A display designated as A, B, C, or D that has pictures at the top and text at the bottom. A and B boards are joined side-by-side and positioned with the joint jutting outward. C and D boards are similarly paired and positioned
Station	A site designated as #1 – #10 that contains 4 boards, with the C/D pair positioned to the right of the A/B pair
Readable	The entire text on a board is brought into clear focus via avatar positioning
Panning	Participant rotates the camera view while remaining at a static location
Blockage	The avatar's position partially blocks from view an otherwise readable board's text

Coding of subgroup behaviors. In order to conduct a visual analysis of participant behavior during their completion of the virtual environment task, the computer screens of a subsample of nine participants were video-recorded during their participation in the research trial. The videos were initially viewed several times at regular speed to allow for an overview of participant behavior in the virtual environment. The components of participants' *primary*

Table 4. Components of Primary Navigational Strategy

Component	**Definition**
Start Point	First station entered by the participant after entering the Museum
Initial Direction	Spatial movement from 1st station/cluster to the 2nd (e.g. forward, clockwise, counter-clockwise)
End Point	Last station entered by the participant prior to exiting the Museum
Visitation Sequence	Sequential list of all stations entered by the participant
Revisits	Stations passed through more than once
Viewing Sequence	Sequential list of all boards made readable for 3+ seconds by the participant
Re-views	Boards made readable for 3+ seconds more than once, including incidences of multiplication

strategies for navigating the virtual environment were then identified. A list of the terms used for describing the strategies is provided in Table 3, while the components of the primary strategies are listed in Table 4. During the initial overview of the videos, seven behaviors not readily apparent in the digital log data were observed and coded. These behaviors were classified as *secondary strategies*. The seven secondary strategies and their definitions are detailed in Table 5. Each of the nine videos was later viewed individually for the purpose of recording participants' use of primary and secondary strategies.

Reading rate. For the secondary strategies of bypassing, skipping, multiplication, and pivoting, a time allotment of three seconds per board was used. This time allotment was calculated in two ways, and was considered to be the minimum time required for a participant to meaningfully interact with the text on a board. In the first calculation, the average reading rate determined by Mpofu (2016) in a study of student computer and mobile devices for learning. Student reading rates were calculated for each of the devices, and an average reading rate for the ten participants in the computer condition was derived as 106 words per minute, while the average reading rate for the ten participants in the paper condition was derived at 150 words per minute. (Mpofu, 2016, p. 931). The four shortest segments of text material on the information boards for the current study were isolated and the word count for each of these four boards was tabulated. The shortest word count was 13 words, which was then compared with Mpofu's (2016) derived average reading rates to determine the average length of time it could be anticipated that it would take a post-secondary student to read the shortest information board in the current study. This anticipated average time to read the shortest board if using a computer-delivered format was derived using the following calculation: [13 x 60] / 106 = 7.36 seconds.

Table 5. Secondary Strategies

Strategy	Definition
Bypass	Readability opportunities maintained for less than 3 seconds
Skip	Boards that were not made readable for 3+ seconds at any point during the entire task, including incidences of unresolved blockage
Multiplication	Two or more boards are made simultaneously readable for 6+ seconds
Pivot	Panning from a static spatial location to create a sequence (2 or more) of boards that are made readable for 3+ seconds each
Resolved Blockage	Blocked text is revealed solely by panning
Complex Blockage	Avatar repositioning is required to reveal blocked text
Unresolved Blockage	Blocked text is not revealed

The anticipated average time to read the shortest board if using a paper format was derived using the following calculation: [13 x 60] / 150 = 5.2 seconds.

The second method of calculation for the three-second reading time allotment involved timing six post-secondary students during their reading of a paper format of each of the four shortest information boards. The students represented four different post-secondary institutions and ranged from one to six years of completed post-secondary education. The results of the timed readings were averaged for each student, and then averaged across students. The average reading time for the shortest board (13 words) was 3.42 seconds, while the overall average for all four boards was 4.01 seconds. Given the above calculations, it was determined that for the current study, a participant who caused an information board to be made readable for less than three seconds was unlikely to have had time to interact with the textual material on the board in a meaningful way.

Behavioral microanalysis. After identifying the target behaviors, a behavioral microanalysis was conducted on the nine videos, which were systematically reviewed according to a precise protocol that allowed the primary strategies to be identified for each participant, and the secondary strategies to be quantified with regard to the frequency of their occurrence. The protocol for identifying and quantifying the behaviors is detailed in Table 6.

Interrater verification. An independent rater was engaged to validate the accuracy of the observation and interpretation of the secondary strategies identified in this study. The independent rater viewed five minutes (approximately 5% of the total video footage) of a single video that was selected through a process of random number generation. With one exception – rather than watching the video twice and watching for multiple strategies, the researcher viewed the video six times and watched for a single secondary strategy during each viewing – the researcher applied the stated protocol to the observation and quantification of six of the secondary strategies used by the randomly-selected participant in the video. The results of the primary data collection were compared with that of the interrater, and a Pearson's correlation was calculated (r=.954). The results of this analysis served to validate the integrity of the data collection process.

Table 6. Video Data Collection Protocol

Viewing Instructions	Strategy	Recording Format	Additional Instructions
View video while clicking 'pause' button, at least once per second, to identify:			
	Start point and end point	Record by station number	
	Initial direction		
	Visitation sequence	Record by station number, separated by commas	
	Viewing sequence	Record by board ID (e.g. 3A), separated by commas	In the case of Multiplication, record IDs in numerical/alphabetical order
	Bypasses	Record by timestamp, separated by commas	

	Skips	Record by timestamp, separated by commas	
			Verify the occurrence of all board IDs, either within the viewing sequence or in the tally of skips
	Multiplications	Record by timestamp, separated by commas	
View video at regular speed, pausing as needed, to identify:			
	Pivots	Record by timestamp, separated by commas	
	Resolved, complex, and unresolved blockages	Record by timestamp, separated by commas	
			Bold any station numbers that occur more than once in the visitation sequence; total the number of bolded items and record the total under revisits

	Bold any board ID numbers that occur more than once in the viewing sequence; total the number of bolded items and record the total under re-views
	Total the number of occurrences for each secondary strategy

Case studies. Despite concerns about the validity of inferential results when using small sample sizes, Poole (2017) pointed out that "small observational studies … are a valuable resource … because of the hypotheses they generate and for the descriptive data they provide" (p. 576). Ying (1989, in Larrinaga, 2017) explained that in research situations where there "is no clear and singular result" (p. 151), case study emerges as a viable methodology for exploring the data. Elo, et al., (2014) state that "There is no commonly accepted sample size for qualitative [case] studies because the optimal sample depends on the purpose of the study, research questions, and richness of the data" (p. 4). As such, the video analysis of the small subsample of participants in the current study offered a rich – and rare – wealth of information that proved to be best extracted and understood through the use of a case study approach.

Case study is considered a valuable research approach in a variety of disciplines, including business (Larrinaga, 2017), counselling (Scholl, 2017), healthcare (Atchan, Davis, & Fourer, 2016), nursing (Elo, et al., 2014, Harrison & Mills, 2016, Houghton, Casey, & Smyth, 2017), public health (Dinour, Kwan, & Freudenberg, 2017), and education (Bartlett & Bartlett, 2016, Miles, 2015), including the Scholarship of Teaching and Learning (SoTL) (Pearson, Albon, & Hubball, 2015). Of particular relevance to the objectives of the current study is the perspective that case study is a "major methodological player in educational research" (Periera & Valance, in Miles, 2015, p. 309). Case study can take exploratory, descriptive, or explanatory approaches to research (Yin, 2014, in Pearson, et al, 2015) that do not shy away from complexity (Harrison & Mills, 2016, Houghton, et al., 2017, Yin, 2014, in Atachan, et al., 2016), allowing data to be generated from a number of sources (Harrison & Mills, 2016) through the employment of a variety of collection methods (Houghton, et al., 2017, Larrinaga, 2017, Miles, 2015, Pearson, et al., 2015). Case studies are "crafted" (Miles, 2015, p. 312) by the researcher, who must come to terms with ambiguity (Larrinaga, 2017) in order to decide which information is important, and who plays a critical role with regard to determining the nature of the data that is generated (Larrinaga, 2017, Miles, 2015).

Given that case studies offer the possibility of maximizing the value of a small sample size by providing opportunity to look deeply (Atchan, et al., 2017, Miles, 2015) at the questions of "Why?" (Dinour, et al., 2017) and "How?" (Pearson et al., 2015) rather than broadly at the questions of "What?" and "How much?" (Larrinaga, 2017), it was determined that an exploratory case study of the subsample would be undertaken from an approach that would primarily focus on the quantitative data (Pearson, et al., 2015) collected for each of the nine participants. Exploratory studies are conducted when a relatively new type of data is being looked at in the manner similar to that of a "pilot study" (Yin, 2014, in Pearson, et al., 2014, p. 3) that can help to inform future research. As the in-depth observation of student behavior – viewed and analyzed by the microsecond – is very rare in the field of education, this study functions as an opportunity to learn from participants' behavior and to introduce ideas that will inform future study in the emerging field of teaching and learning in virtual environments.

Each participant in the subsample was considered as an individual case study. A random number generator was used to assign nominal designations to each of the nine participants, and these nominal designations (e.g. Case One) were used for case study identification. The case study analysis focused on investigating the profile membership of participants alongside the strategies they used to navigate the particular condition to which they had been randomly assigned.

Results

Cluster Formation

Data on the four variables of video game experience (VGE), social media experience (SME), perceived spatial skill (PSS), and demonstrated spatial skill (DSS), was collected from 134 participants; however, the data from one participant in the clustered condition was lost due to a technical malfunction. The final analyses were therefore conducted on the data from 133 participants. Four distinct clusters emerged during the application of the Ward's method of agglomerative hierarchical cluster analysis, and the four-cluster solution was validated by application of the k-means algorithm. The number of participants in each cluster, the mean scores achieved by each cluster on each variable, and the range between cluster means are shown in Table 7, which also includes the population values. Clusters with a mean score above the population mean on a particular variable are considered to have achieved 'high' scores for that variable, while clusters with scores falling below the population mean are considered to have 'low' scores.

As part of the k-means analysis, an ANOVA was conducted on the four variables used to define the clusters. The results of the ANOVA revealed that all four of the variables were significant at the 05 level: video game experience ($F(3, 129) = 126.670$, $p < .001$)), social media experience ($F(3, 129) = 4.221$, $p = .007$), perceived spatial skill ($F(3, 129) = 8.114$, $p < .001$) and demonstrated spatial skill ($F(3, 129) = 122.762$, $p < .001$). These results confirmed that each variable had a significant role to play in distinguishing between the groups. However, video game experience and demonstrated spatial skill evidenced far higher F-values than did perceived spatial skill and social media experience.

A post hoc Tukey test reported the distance between the cluster means for each variable. There were six measures of distance in total. The Tukey test confirmed that the distances between all means for video game experience were significant at a .05 level. For demonstrated spatial skill, the distances between all means except for one (the distance between cluster two and cluster four) were also statistically significant. However, this was not true for the other two variables: Only three distances (between clusters one and two; clusters two and three; and clusters two and four) for the PSS were significant at a .05 level, and only one distance between means (between clusters two and four) was statistically significant for the SME. As such, particular attention must be paid to the variables of video game experience and demonstrated spatial score when interpreting and describing the student profiles.

Data from the cluster analysis was used to identify four distinct clusters which emerged amongst the research sample of 133 students. The four clusters, visually represented by the bar graph in Figure 5, were determined to represent four defined student profiles and were assigned profile titles, followed by descriptive names relating to their primary distinguishing characteristics. Note: Where differences were reported for comparative purposes as a part of the profile description, the differences were calculated from the cluster with the next closest mean in sequence.

Table 7. Cluster Mean Scores

	N	VGE	SME	PSS	DSS
Population	133	31.25	29.89	49.79	74.12
Cluster 1	17	77.21 High	26.84 Low	54.29 High	70.59 Low
Cluster 2	21	59.52 High	41.96 High	35.92 Low	94.84 High
Cluster 3	34	23.53 Low	30.88 High	56.95 High	38.24 Low
Cluster 4	61	13.01 Low	26.02 Low	49.32 Low	87.98 High
Range between highest and lowest	44	64.20	15.94	21.03	56.60

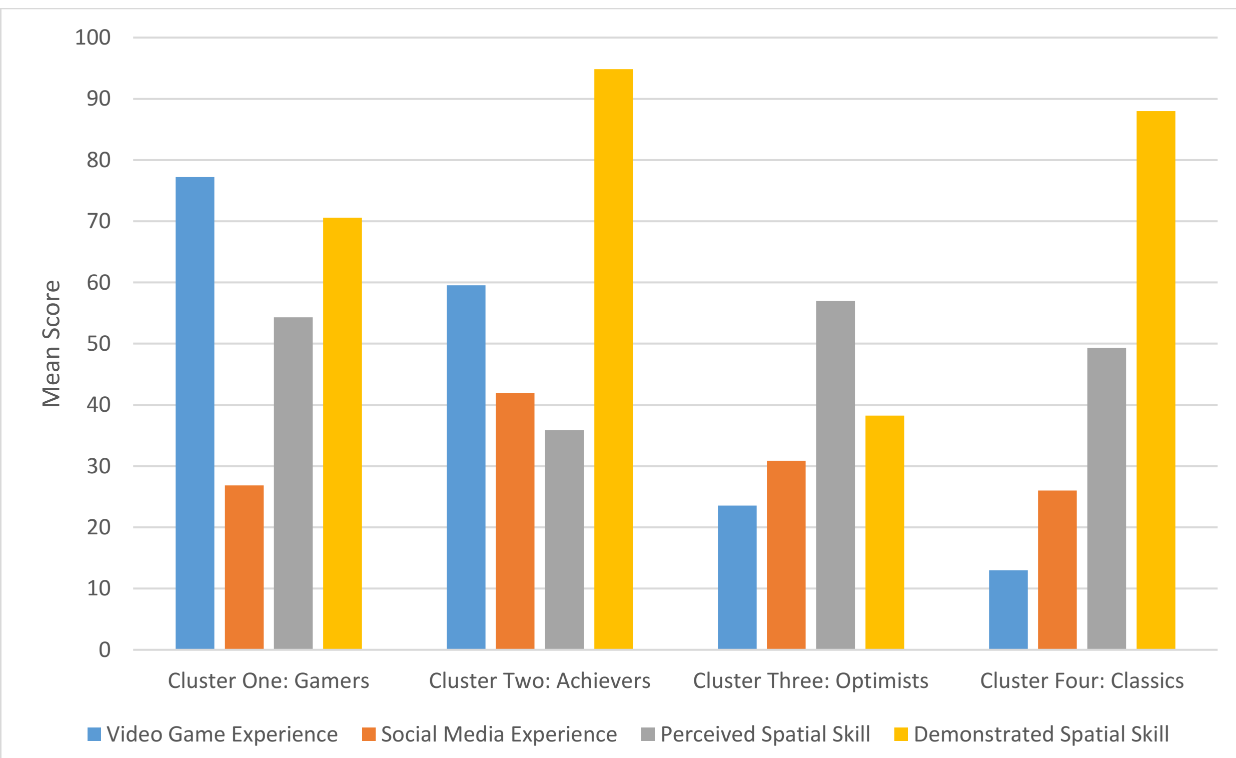
Cluster One: The Gamers. The first cluster identified by the analysis was the smallest cluster, having only 17 members (approximately 13% of the total population). Cluster One was designated as Student Profile One. These students reported the highest level of expertise in the entire sample with regard to playing video games (M=77.21, Mean difference=17.682), but evidenced low levels of social media experience (M=26.84). Although their demonstrated spatial skill (M= 70.59) is below the mean, their perceived (M=54.29) and demonstrated spatial skills (Range=16.30) have the highest levels of concurrence amongst all of the profiles, suggesting that their level of confidence is well-matched to their abilities. Students who were identified as members of Profile One are hereafter referred to as the *Gamers*.

Cluster Two: The Achievers. The second cluster was also a relatively small cluster, with a membership of 21 (approximately 16% of the total population). Cluster Two was designated as Student Profile Two. This group of students had the highest level of demonstrated spatial skill (M=94.84, Mean difference=6.863) amongst the entire sample, but the lowest level of perceived spatial skill (M=35.92, Mean difference= -13.402), with the scope of the difference (Range=58.92) suggesting that they may underestimate their own capability. Similar to their colleagues in Profile One, students in Profile Two demonstrated a high level of video game experience (M=59.52) but, unlike the students in the first profile, members of Profile Two paired their gaming expertise with the highest level of social media experience (M=41.96, Mean difference=11.082) amongst the entire sample of participants. Students who were identified as members of Profile Two are hereafter referred to as the *Achievers*.

Cluster Three: The Optimists. The third cluster was a somewhat larger cluster, having 34 members (approximately 26% of the total population). Cluster Three was designated as Student Profile Three. The students in this profile were the only group to report higher levels of perceived spatial skills (M=56.95) than they were able to demonstrate on the SOT (M=38.24), indicating a noticeable discrepancy (Range=18.71) between their perception of their spatial capability and their actual demonstration of it. In direct contrast to the individuals in Profile Two, students in Profile Three have the highest perception of their own skill amongst the groups, albeit by a slim margin (Mean difference=2.661), but it is paired with the lowest level in the sample (Mean difference=32.353) of spatial skill demonstration. In addition, students in Profile Three have low video game experience (M=23.53), and their social media experience (M=30.88) – while strictly speaking one of the two 'high' scores in the population – is hardly discernable from the profiles that fall into the 'low' SME categorization (Mean difference=4.044). Students who were identified as members of Profile Three are hereafter referred to as the *Optimists.*

Cluster Four: The Classics. The fourth cluster is by far the largest cluster, with 61 members (approximately 45% of the total population). Cluster Four was designated as Student Profile Four. The bar graph for this cluster is the most polarized in appearance, as the actual spatial skill (M=87.98) of students in this profile, as demonstrated on the paper-and-pen SOT, is very high. However, in a pattern similar to that demonstrated by students in Profile Two, the perceived spatial skill (M=49.32) of these students is dramatically lower (Range=38.66). In

Figure 5. Cluster Formations



addition, the video game experience (M=13.01) and social media experience (M=26.02) of Profile Four members are substantially lower than both measures of their spatial capacity, placing students in Profile Four at the lowermost level (Mean Differences = -10.517 and -0.814, respectively) for the population on both types of technology usage. Students who were identified as members of Profile Four are hereafter referred to as the *Classics.*

Analysis of Variance (ANOVA). As part of the k-means analysis, an ANOVA was conducted on the four variables used to define the clusters. The results confirmed that all of the variables were statistically significant at .05 level of significance, indicating that each variable had an important impact on distinguishing between the groups. Elwin, et al. (2017) conducted a Tukey post hoc analysis to compare clusters; the same was done in this study to help identify the distance between cluster means for each variable.

Tukey post hoc: Cluster comparison. The Tukey analysis revealed dramatic differences in scores on video game experience between the profiles. The Gamers had much higher scores on video game experience than the Classics (D = 64.194), which was the highest difference between any two profiles on any of the four variables. However, the Gamers also had much more experience than the Optimists (D = 53.676), while the Achievers were noticeably more experienced at video games than both the Classics (D = 46.512), and the Optimists (D = 35.994). The Gamers outdid the Achievers by a smaller margin (D = 17.682), but even the Optimists and the Classics, who were the closest together with regard to their video game experience, still had a noteworthy disparity (D = 10.517).

In direct contrast to their diversity with regard to video game experience, the four profiles were quite similar with regard to their scores on social media experience. The Achievers were the high scorers on social media, trumping the Classics (D = 15.940), the Gamers (D = 15.126), and the Optimists (D = 11.082); however, these differences were not highly substantial. The Optimists barely scored higher than the Classics (D = 4.858) or the Gamers (D = 4.044). Most notably, the difference in social media use between the Gamers and the Classics was almost nonexistent (D = 0.814).

With the exception of the Achievers, the four profiles were also quite similar with regard to their perceived spatial skills. The Achievers were noticeably different from all of the other profiles, all of whom incurred differences of 7.626 or less between them. However, the Achievers' perceived spatial skill was markedly lower than the Optimists (D =21.028), and the Gamers (D = 18.367), along with the Classics (D = 13.402).

When looking at demonstrated spatial skill, the scores between the profiles once more dramatically diverged. The greatest disparity in demonstrated spatial skill was between the Optimists, who were dramatically lower than the Achievers (D = 56.606), and also well behind the Classics (D = 49.743), and the Gamers (D = 32.353). The Achievers demonstrated noticeably higher levels of spatial skill than the Gamers (D = 24.253), who also fell behind the Classics (D = 17. 390). The Achievers scored higher than the Classics (D = 6.83), but only by a fairly unremarkable margin.

Case Studies

Each of the nine participants in the video-recorded subsample was considered as an individual case study, and randomly generated nominal designations were used for case study identification. Investigation of each case involved reviewing the results of the quantitative analyses and then exploring each participant's profile membership alongside the strategies the participant used to navigate the particular spatial condition to which they were assigned. Results of the quantitative data is detailed below. Further investigation regarding the significance of the case study results can be found in the *Discussion, Part II* section.

Case One. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *optimist* student profile and also participated in the linear spatial condition. Case One started at station one and travelled forward, moving sequentially through each station in numerical order and finishing at station ten. The visitation sequence employed by Case One to engage with the ten stations was: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Case One did not conduct any revisits of the stations. The viewing sequence employed by Case One to navigate the information on the 40 boards was: 1A, 1D, 2A, 2B, 2C, 3B, 4C, 4D, 8C. Case One did not view any of the boards a second time, which was a notable departure from the group average of 4.8 re-views. Also of particular note is that Case One had the highest rate of skips amongst the sample, skipping 31 of the 40 boards and failing to make them readable at any point during the task. This rate of skipping was strikingly higher than the group average of 5.7 skips; in fact, Case One's rate of skipping was conspicuously different from the rest of the subsample, and it increased the entire group average by 3.2 skips (average was 2.5 skips with Case One's data excluded from the analysis). Also of note is that Case One resolved only four incidences of blockage, which was the lowest rate of resolution amongst the sample and was markedly lower than the group average of 13.6 resolutions. However, Case One also incurred no complex blockages, which tied Case One with another participant for the lowest rate of complex blockages amongst the sample population, who averaged only 3.6. Case One failed to resolve four blockages. This brought Case One's total number of blockages incurred to eight, the lowest number of total blockages amongst the sample and well below the group average of 21.2. Case

One also bypassed 48 opportunities to interact with content on a readable board, effected two incidences of multiplication, and conducted two pivots.

Case Two. This case study explores the behavior of the only participant who was a part of the videotaped subsample and fell with the *gamer* student profile. Case Two completed the VE tasks in the linear spatial condition, starting at station one and then travelling forward, moving sequentially through each station in numerical order and finishing at station ten. The visitation sequence employed by Case Two to engage with the ten stations was: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. The viewing sequence employed by Case Two to navigate the information on the 40 boards was: 1C, 1A, 1B, 1C, 1D, 2B, 2C, 2A, 2D, 3C, 3B, 3C, 3D, 3B, 3C, 3A, 3D, 4B, 4C, 4A, 4D, 5B, 5C, 5D, 6C, 6B, 6C, 6A, 6B, 6D, 7C, 7B, 7C, 7D, 8C, 8B, 8C, 8D, 9A, 9B, 9C, 9D, 10A, 10C, 10B, 10D. Case Two did not conduct any revisits of stations, but did view eight of the boards a second time. Of particular note is that Case Two did not resolve eight blockages, which was the highest rate of unresolved blockages amongst the subsample, who averaged 4.6 unresolved blockages. Case Two did resolve 16 other blockages, also experiencing four complex blockages for a total of 28 blockages. Case Two bypassed 45 opportunities to interact with content on a readable board, and skipped three boards. Case Two also effected seven incidences of multiplication, and conducted five pivots.

Case Three. This case study explores the behavior of one of the two participants in the videotaped subsample who fell with the *classic* student profile and also participated in the clustered spatial condition. Case Three started at station nine and then initially travelled clockwise through the virtual environment, moving through each cluster and then revisiting station nine before exiting the virtual environment. Case Three was one of only three of the participants in the sample to conduct a station revisit. The visitation sequence employed by Case

Three to engage with the ten stations was: 9, 10, 6, 5, 4, 8, 7, 3, 2, 1, 9. The viewing sequence employed by Case Three to navigate the information on the 40 boards was: 9A, 9B, 9D, 9B, 9D, 10A, 10C, 10B, 10C, 10D, 6A, 6B, 6C, 6D, 5A, 5B, 5C, 5D, 4A, 4B, 4C, 4D, 8A, 8B, 8C, 8D, 8D, 7A, 7B, 7D, 3A, 3C, 3B, 3C, 3D, 2B, 2C, 2D, 1A, 1D, 1B, 1C, 1B, 9A, 9B, 9C. Case Three viewed eight of the boards a second time. Of particular note is that Case Three bypassed only 16 opportunities to interact with content on a readable board, which was by far the lowest rate amongst the subsample, who averaged 48.8. Case Three did not resolve five blockages, but did resolve 17 other blockages, also incurring one complex blockage for a total of 19 blockages. In addition, Case Three skipped two boards, effected five incidences of multiplication, and conducted one pivot.

Case Four. This case study explores the behavior of the only participant who was a part of the videotaped subsample and fell within the *achiever* student profile. The individual in this case study completed the virtual environment tasks in the random spatial condition, starting at station one and then initially travelling counter-clockwise through the virtual environment, moving through each station and ending at station ten before exiting the virtual environment. The visitation sequence employed by Case Four to engage with the ten stations was: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Case Four did not conduct any revisits of stations. The viewing sequence employed by Case Four to navigate the information on the 40 boards was: 1B, 1C, 1A, 1D, 2A, 2B, 2C, 2D, 3A, 3B, 3C, 3D, 4A, 4B, 4C, 4D, 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D, 7A, 7B, 7C, 7D, 8A, 8B, 8C, 8D, 9A, 9B, 9C, 9D, 10A, 10B, 10C, 10D. Case Four did not skip any of the boards, a marked departure from the group average of 5.7, nor did Case Four view any of the boards a second time, thereby incurring another perceptible difference from the rest of the his cohort, who

averaged 4.8 re-views. Also of particular note is that Case Four conducted 17 pivots, which was the highest number of pivots amongst the subsample, who averaged 5 pivots.
Case Four did not resolve three blockages but did resolve ten other blockages, also incurring two complex blockages for a total of 15 blockages. Case Four also bypassed 46 opportunities to interact with content on a readable board, and effected two incidences of multiplication.

Case Five. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *optimist* student profile and also participated in the random spatial condition. Case Five started at station ten and then initially travelled clockwise, moving through each station and ending at station one before exiting the virtual environment. The visitation sequence employed by Case Five to engage with the ten stations was: 10, 9, 8, 7, 6, 5, 4, 3, 2, 1. Case Five did not conduct any revisits of stations, but did view nine of the boards a second time, which was the highest number of reviews amongst his cohort, who averaged 4.8 re-views. The viewing sequence employed by Case Five to navigate the information on the 40 boards was: 10A, 10B, 10A, 10C, 9A, 9C, 9B, 9C, 9D, 8C, 8A, 8B, 8D, 7A, 7C, 7B, 6A, 6C, 6B, 6C, 6D, 5A, 5B, 5C, 5B, 5D, 4A, 4D, 4B, 4A, 4B, 3A, 3A, 3B, 3C, 3D, 2C, 2A, 2B, 2C, 2D, 2C, 1C, 1A, 1B, 1C, 1B. Although Case Five did not resolve four blockages, it is of particular note that Case Five did resolve 21 other blockages, which was the highest rate of blockage resolution amongst the subsample, who averaged 13.6 resolutions. At eight complex blockages, Case Five also tied with another participant for the highest rate of blockages that required spatial movement to resolve, a rate which was notably higher than the group average of 3.6. Case Five had a total number of 33 blockages during the virtual environment task. Case Five bypassed 57 opportunities to interact with content on a readable board, and skipped four boards. Case Five also effected four incidences of multiplication, and conducted two pivots.

Case Six. This case study explores the behavior of one of the two participants in the videotaped subsample who fell with the *classic* student profile and also participated in the clustered spatial condition. Case Six started at station one and then initially travelled counter-clockwise, moving through each cluster and then revisiting station one before exiting the virtual environment. Case Three was one of only three of the participants in the sample to conduct a station revisit. The visitation sequence employed by Case Six to engage with the ten stations was: 1, 2, 3, 7, 8, 6, 5, 4, 9, 10, 1. The viewing sequence employed by Case Six to navigate the information on the 40 boards was: 1D, 1A, 1B, 1C, 1D, 2D, 2B, 2C, 2B, 2D, 2A, 3D, 3B, 3A, 7B, 7D, 8A, 8B, 8C, 6A, 6B, 6D, 6C, 5A, 5C, 5B, 5C, 4A, 4B, 4A, 4B, 4C, 4D, 9A, 9B, 9C, 9D, 10A, 10C, 10B, 10D, 1B. Case Six viewed six of the boards a second time. Of particular note is that Case Six bypassed 90 opportunities to interact with content on a readable board, which was the most bypassing done by any participant within the subsample, who averaged 48.8 bypasses. Case Six also effected nine incidences of multiplication, which was the highest rate of multiplication amongst his cohort, who averaged only 4.8. Case Six did not resolve seven blockages, but did resolve 20 other blockages. Case Six also incurred seven complex blockages for a total of 34 blockages, which was the greatest total number of blockages amongst the subsample, who averaged only 21.2 blockages. Case Six also skipped four boards., and conducted three pivots.

Case Seven. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *classic* student profile and also participated in the random spatial condition. Case Seven was the only participant to be 'dropped' into a foyer (rather than into station one, as in the linear condition) and to begin navigating the virtual environment at a station which was not positioned directly next to the sign with the exit directions. Instead, Case Seven crossed the foyer to begin at station four. From that point, Case Seven initially travelled counter-clockwise, moving through a total of five stations before briefly revisiting station four (essentially 'peering' into the station but not actually entering it) and then revisiting station five. Case Seven then continued counter-clockwise through the other clusters, and ended at station ten before exiting the virtual environment. The visitation sequence employed by Case Six to engage with the ten stations was: 4, 5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Case Seven was one of only three of the participants in the sample to conduct a station revisit. The viewing sequence employed by Case Seven to navigate the information on the 40 boards was: 4D, 4B, 4C, 4A, 4B, 4A, 4B, 4D, 5B, 1B, 1D, 2C, 2A, 2B, 2D, 2B, 3A, 3B, 3C, 3D, 5A, 5C, 5D, 6A, 6B, 6C, 7A, 7A, 7B, 7C, 7D, 8A, 8B, 8C, 8D, 9A, 9C, 9B, 9C, 9D, 9D, 10A, 10C, 10D. Case Seven viewed eight of the boards a second time. Of particular note is that Case Seven was the only participant amongst the subsample who did not conduct any pivots, which was considerably different than the group average of five pivots. Case Seven also incurred eight complex blockages, which tied Case Seven with another participant for the highest number of blockages that required spatial movement for resolution. This number of complex blockages was substantially higher than the group average of 3.6. Case Seven resolved 14 other blockages, also incurring three unresolved blockages for a total of 25 blockages. Case Seven bypassed 52 opportunities to interact with content on a readable board, and skipped four boards. Case Seven also effected eight incidences of multiplication.

Case Eight. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *classic* student profile and also participated in the linear spatial condition. Case Eight started at station one and then initially travelled forward, moving through each station in a numerically sequential fashion before ending at station ten and exiting the virtual environment. The visitation sequence employed by Case Eight to engage with the ten stations was: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. Case Eight did not conduct any revisits of stations. The viewing sequence employed by Case Eight to navigate the information on the 40 boards was: 1B, 1A, 1C, 1A, 1D, 2A, 2B, 2D, 3A, 3B, 3C, 3D, 4A, 4C, 4D, 4B, 5A, 5C, 5B, 5D, 6A, 6B, 6C, 6A, 6D, 7A, 7B, 7C, 7D, 8C, 8B, 8D, 9A, 9B, 9B, 9C, 9D, 10A, 10B, 10C, 10D. Case Eight viewed three of the boards a second time. Of particular note is that Case Eight incurred no complex blockages, tying with another participant for the lowest number of complex blockages amongst his cohort, who averaged 3.6 complex blockages. Case Eight did not resolve six blockages, but did resolve eleven other blockages for a total 17 blockages. Case Eight bypassed 44 opportunities to interact with content on a readable board, and skipped two boards. Case Eight also effected three incidences of multiplication, and conducted seven pivots.

Case Nine. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *optimist* student profile and also participated in the clustered spatial condition. Case Nine started at station nine and then initially travelled clockwise, moving through each cluster and ending at station ten before exiting the virtual environment. The visitation sequence employed by Case Nine to engage with the ten stations was: 9, 10, 6, 5, 4, 8, 7, 3, 2, 1. Case Nine did not conduct any revisits of stations, but did view one of the boards within a station a second time. The viewing sequence employed by Case Nine to navigate the information on the 40 boards was: 9A, 9B, 9C, 9D, 10A, 10B, 10C, 10D, 6A, 6B, 6C, 6D, 5B, 5C, 5D, 4A, 4B, 4C, 4D, 8A, 8B, 8C, 8B, 8D, 7A, 7B, 7C, 7D, 3A, 3B, 3C, 3D, 2A, 2B, 2C, 2D, 1A, 1B, 1C, 1D. It is notable that, by causing multiplication to occur only once, Case Nine effected the lowest number of multiplication instances amongst the subsample, who averaged 4.8. Case Nine also left only one blockage unresolved, which was the lowest number of unresolved blockages amongst his cohort, who averaged 4.6 unresolved blockages. Case Nine resolved nine other blockages and incurred two complex blockages, for a total of 12 blockages. Case Nine bypassed 42 opportunities to interact with content on a readable board, skipped only one board, and conducted 12 pivots.

Discussion Part I: Quantitative Analyses

This study was guided by two primary research objectives, the first of which related to the development of a classification of student characteristics. This classification was accomplished by conducting a cluster analysis, which was then rolled forward to facilitate the second primary research objective: the development of a deeper understanding of a small participant subsample through the use of a qualitative case study analysis (discussed in the *Discussion Part II: Qualitative Analysis* section).

First Research Question: Student Profiles

The first objective was to investigate and define the presence of distinctive homogenous groupings – *profiles* – within a sample of students with regard to their computer experience and spatial abilities. The primary research question associated with this objective was: "Does undergraduate students' prior exposure to three elements of computer usage – software awareness, video game experience and social media usage – in combination with their perceived and demonstrated spatial skills allow for the classification of students into stable groupings which can then function as student profiles?" Three secondary research questions helped to operationalize the primary question:

3. If the answer to the primary question is affirmative, how many profiles are optimally identified within the analyzed sample of students?

4. If the answer to the primary question is affirmative, what are the membership statistics for the number and ratio of students attributed to each profile?
5. If the answer to the primary question is affirmative, what are the stable characteristics of each of the student profiles?

Cluster analysis is a multi-stage statistical process requiring the determination of initial results and associated discussion of the implications prior to determining the next stage of statistical analysis. As such, the complete investigative process which allowed for exploration of the above research questions is explained in detail in the *Methods* section, subsection *Cluster Analysis*. For the reader's convenience, a synopsis is reprinted here. Analysis was conducted on the premeasure scores of 133 participants, yielding four distinct clusters. The clusters were examined to discern their unique characteristics, and from them emerged four student profiles: The *Gamers*, the *Achievers*, the *Optimists,* and the *Classics*.

Profile One: The Gamers. The first profile identified by the cluster analysis was the smallest, having only 17 members (approximately 13% of the total population). These students reported the highest level of expertise with video games in the entire sample, but evidenced low levels of social media experience. Although their demonstrated spatial skill is below average, their perceived and demonstrated spatial skills have the highest levels of concurrence amongst all of the profiles, suggesting that their level of confidence is well-matched to their abilities.

Profile Two: The Achievers. The second profile was also relatively small, with a membership of 21 (approximately 16% of the total population). This group of students had the highest level of demonstrated spatial skill amongst the entire sample, but the lowest level of perceived spatial skill, with the dramatic difference between the two scores suggesting that these students may underestimate their own capability. Demonstrating similarity with the Gamers, the

Achievers demonstrated a high level of video game experience. However, unlike the Gamers, the Achievers paired their gaming expertise with the highest level of social media experience amongst the entire sample of participants.

Profile Three: The Optimists. The third profile was somewhat larger, having 34 members (approximately 26% of the total population). The students in this profile were the only group to report higher levels of perceived spatial skill than what they were able to demonstrate on the Spatial Orientation Test, indicating a noticeable discrepancy between their perception of their spatial capability and their actual demonstration of it. In direct contrast to the Achievers, the Optimists have the highest perception (amongst the entire sample) of their own skills, but this perception is paired with the lowest level of spatial skill demonstration. In addition, the Optimists have little video game experience, and their social media experience – while strictly speaking one of the two 'high' scores in the population – is barely discernable from the profiles that fall into the 'low' social media categorization.

Profile Four: The Classics. The fourth profile has by far the largest membership, with 61 members (approximately 45% of the total population). The bar graph segment (see *Figure 3*) for this profile is the most polarized in appearance of all the student profiles. The actual spatial skill of the Classics, as demonstrated on the paper-and-pen Spatial Orientation Test, is very high. However, in a pattern similar to that demonstrated by the Achievers, the perceived spatial skill of these students is dramatically lower. In addition, the Classics' levels of experience with video games and social media are substantially lower than both measures of their spatial capacity, placing the Classics at the lowermost level for the population on both types of technology usage.

Summary of cluster analysis. The first research question which the current study sought to investigate was whether undergraduate students' exposure to software, video games, and social media – in combination with perceived and demonstrated spatial skills – allowed for classification of students into distinctive student profiles with stable characteristics. Analysis of the data from 133 undergraduate participants who completed premeasures related to the constructs of computer and spatial skills revealed four student profiles with distinctive characteristics. The Gamers have the highest video game experience, but the smallest membership. Achievers are well-versed in both video games and social media, but are only somewhat greater in number than the Gamers. Optimists, with almost twice the membership of Gamers, demonstrate low levels of skill or experience in all areas, yet perceive themselves as spatially well-skilled. The Classics demonstrate exceptional spatial skill on a pen-and-paper task and have by far the largest student profile membership, but possess the least experience with video games or social media.

The rate of membership in each of the clusters can be thought of as surprising, given the high rate of membership in a cluster whose characteristics include low video game and social media experience. An unexpected disparity appears to occur when these characteristics are compared to the common perception that modern universities are home to the media-savvy millennial post-secondary student. Indeed, the *Literature Review* for the current study includes many references (e.g. Bauer, 2007, Broussard, 2009, Grosch, Berger, Gidion & Romeo, 2014) to exactly that perspective. Although the sample of students included in the current cluster analysis is a reasonable size at 133 students, it remains a very small fraction of the post-secondary student population and is composed of a largely homogeneous cohort of undergraduate students from two closely-related educational psychology classes. As such, although it is important to note the results of this analysis, further study should be conducted in order to replicate these results on a larger scale with a more diverse population of students.

Discussion Part II: Qualitative Analysis

A quantitative analysis (e.g. ANOVA) was not conducted to investigate the relationship between the video-recorded participants' student profile and their observed behaviors (secondary strategies), as the sample size of the video-recorded participants that were associated with each profile was extremely small (as low as a single participant per group). In addition, a 400% difference in group size created substantial validity concerns. However, the following qualitative case study analysis allowed for a deeper investigation of the participants' behavior in conjunction with spatial condition and cluster membership.

Second Research Question: Case Studies

The second primary research objective guiding this study was to conduct an in-depth exploration of the behavior of individuals from diverse student profiles while they undertake tasks in dissimilar virtual environment spatial conditions. The primary research question associated with this objective was: "Can in-depth exploration of the nature and frequency of identified undergraduate student behaviors, in combination with student profile membership and virtual environment spatial configuration, yield insight into the likelihood of behavioral occurrences during an information-based learning task that takes place in a virtual environment?" Three secondary research questions helped to operationalize the primary question:

1. If the answer to the primary question is affirmative, what is the nature of the behavior employed by an individual with each occurring combination of student profile membership and placement within spatial condition?
2. If the answer to the primary question is affirmative, are there underlying implications that can be suggested by a review of relevant literature?

3. If the answer to question 2 is affirmative, what potential directions for future research can be generated?

Poole (2017) stated that "small observational studies … are a valuable resource … because of the hypotheses they generate and for the descriptive data they provide" (p. 576). Each of the nine participants in the video-recorded subsample was considered as an individual case study, and randomly generated nominal designations were used for case study identification. Investigation of each individual case involved reviewing the results of the quantitative analyses and then exploring each participant's profile membership alongside the strategies the participant used to navigate the particular spatial condition to which they were assigned. As a feature of the ensuing discussion, the profile designation and assigned spatial condition of each case will be regularly identified as a way of 'observing' the potential impact of the spatial condition and the profile characteristics as they are 'lived out' in the observed behavior of the participant. To standardize representation, the identical pronoun will be used for all cases. As the avatar manipulated by participants during the virtual environment task appeared to be a young male adult, the universal pronoun used will be 'he'.

Terms. A number of terms were developed during the course of the current study. These terms are found in Tables 3, 4, and 5, but are summarized below for ease of use in reviewing the case studies. Note: Revisits and re-views, along with start and end points, visitation sequence, and direction of travel are considered as part of a participant's *primary strategy* for navigating the virtual environment. Terms that are designated with an * relate to *secondary strategies* employed by participants as they interacted with the information content displayed on the boards.

1. *Board*: A display designated as A, B, C, or D that has pictures at the top and text at the bottom. A and B boards are joined side-by-side and positioned with the joint jutting outward. C and D boards are similarly paired and positioned.
2. *Station*: A site designated as #1 – #10 that contains 4 boards, with the C/D pair positioned to the right of the A/B pair
3. *Readable*: The entire text on a board is brought into clear focus via avatar positioning Note: For the purpose of expediency during the pursuant discussion, the term *view* is introduced here as an interpretation of the act of making a board readable
4. *Panning*: Participant rotates the camera view while remaining at a static location
5. *Blockage:* The avatar's position partially blocks from view an otherwise readable board's text
6. **Resolved Blockage*: Blocked text is revealed solely by panning
7. **Complex Blockage*: Avatar repositioning is required to reveal blocked text
8. **Unresolved Blockage*: Blocked text is not revealed
9. *Revisits*: Stations passed through more than once
10. *Re-views*: Boards made readable for 3+ seconds more than once, including incidences of multiplication
11. **Bypass*: Readability opportunities maintained for less than 3 seconds
12. **Skip*: Boards that were not made readable for at least 3 seconds, including incidences of unresolved blockage
13. **Multiplication*: 2 or more boards are made simultaneously readable for 6+ seconds
14. **Pivot*: Panning from a static spatial location to create a sequence (2 or more) of boards that are made readable for 3+ seconds each

Implications of blockages. Blockages occurred when a participant positioned the avatar in front of an otherwise-readable board, blocking part of the text on the board. Blockages prevented a participant from interacting with the text on the board in its entirety, not only depriving him of part of the content, but also impairing his ability to put into full context the content that he could see. A high number of incurred blockages may have indicated that the participant experienced difficulty with avatar navigation.

Implications of resolved blockages. Resolved blockages occurred when a participant initially positioned the avatar in front of an otherwise-readable board, but then was able to reveal the blocked text by employing panning alone and without repositioning the avatar. Blockage resolution required a combination of skills, including a fairly high level of finesse at manipulating the camera within the virtual environment. It also required an understanding of the avatar's position in relation to the board and the ability to anticipate how rotating the camera would change the relationship between the board and the avatar. In addition, resolving blockages required a certain level of patience in order to take the time to assess the situation without defaulting to the less salient method of simply trying to move the avatar out of the way.

Implications of complex blockages. Complex blockages occurred when a participant initially positioned the avatar in front of an otherwise-readable board and attempts at panning the camera to reveal the blocked text were not successful. Instead, the participant had to default to spatially repositioning the avatar in order to reveal the blocked text. Participants who experienced a high number of complex blockages appeared to experience some difficulty with both avatar manipulation – having positioned the avatar in an unhelpful position to begin with – and camera manipulation. In addition, they appeared to have some difficulty with anticipating the result of panning the camera or with changing the avatar's position relative to the board, as they often made multiple attempts at resolution before succeeding.

Implications of unresolved blockages. An unresolved blockage occurred when the position of a participant's avatar blocked part of the readable text on a board and the participant did not resolve the blockage. Unresolved blockages were the outcome of one of two prior courses of action: either the participant failed in the attempt to resolve the blockage and simply discontinued the effort, or they did not make the initial attempt and simply allowed the blocked text to remain as is. As a result, the blocked text – and the information it contained – remained inaccessible to the participant and not only prevented him from interacting with the text on the board in its entirety, but also impaired his ability to put into full context the content that could be seen.

Implications of revisits. Revisits are considered to be a part of a participant's primary strategy of navigating the virtual environment. A revisit occurred when a participant returned to a station and re-entered it after having entered that station at least once before. Revisits often appeared to be intentionally conducted just prior to exiting the virtual museum as a form of due diligence which ensured that all stations had been visited at least once. In some cases, multiple boards within the revisited station were made readable, and in other cases, it appeared that the participant simply interacted with the pictures on a board – typically from across the room – as a way to confirm his previous visit.

Implications of re-views. Re-views occurred when a participant made a board readable for a second (or subsequent) time after having already done so once before. Although somewhat similar in nature to revisits (defined above), re-views did not seem to be utilized in the same manner. Whereas revisits gave the impression of being used as a proactive, somewhat methodical strategy, re-views seemed to be more reactive in nature, occurring somewhat haphazardly and without a discernable pattern or in a predictable sequence.

Implications of bypassing. A bypass occurred when a participant made a board readable through positioning of their avatar, but did not sustain the readability long enough (three or more seconds) to interact with the textual information on the board in a meaningful way. This meant that the opportunity to interact with the content was lost and a new instance of readability would have to be generated by the participant, resulting in inefficiency. A high rate of bypasses tended to occur when a participant seemed to have poor management of their camera navigation, wildly swinging the camera and not appearing to know what to focus on. The overall rate of bypasses amongst the sample was quite high at an average of 48.8 bypasses per participant, which was more than 1.2 bypasses per board.

Implications of skipping. Skipping occurred when a board was not made readable at any point during participation in the task. A high rate of skipped content was notable, as it ran counter to the expressly written instruction that read ”Please read all material very carefully and try to remember as much as you can” (see *Method* section for contextual information) given to participants just prior to entering the virtual museum. If the objective of such an instruction was to encourage information retention during the task – as is likely to be true in education – an elevated rate of skipping would work directly against the accomplishment of that objective.

Implications of multiplication. Multiplication occurred when a participant was able to position the avatar in a way that allowed them to make more than one board simultaneously readable, which reduced the need for avatar movement and considerably increased efficiency. The second board was typically either part of the same pair of boards (A/B or C/D), part of a different pair (A/C or B/D), or part of a triple combo (A/B/C or B/C/D). A low rate of multiplication tended to occur when a participant demonstrated poor skills in avatar navigation and/or seemed to be have a low level of awareness of boards other than the one with the most saliency, typically the board immediately 'in front' of him.

Implications of pivoting. Pivoting could be considered the 'gold standard' of virtual environment navigation. Pivoting occurred when a participant was able to position the avatar in a way that allowed him to make one board readable, and then retain the same 'physical' position within the environment while panning the camera to make a second board readable. The second board was typically either part of the same pair of boards (A/B or C/D), part of a different pair (A/C or B/D), or part of a triple combo (A/B/C or B/C/D). Pivoting considerably increased efficiency. A high rate of pivoting tended to occur when a participant seemed to have a strong skill set in both avatar navigation and camera manipulation. Additionally, pivoting seemed to require a level of proficiency in 'reading' the environment and knowing how to position the avatar at the optimum distance from a board in order to anticipate a pivoting opportunity, along with the patience to move into position without 'rushing' the board and getting too close.

Caveat. Studies have found that users of immersive virtual reality often underestimate the length of a distance within the virtual environment (Williams, et al., 2007), and while there are notable differences between immersive virtual reality experiences and non-immersive use of virtual environments, the question can be raised as to whether difficulty with distance estimation may account, at least in part, for a number of the behaviors listed above.

Case One: Optimist-Linear. This case study explores the behavior of the only student from the videotaped subsample who fell within the *optimist* student profile and also participated in the linear spatial condition. Optimist-Linear started at station one and travelled forward through the virtual environment, visiting the stations in a sequential manner until arriving at station ten without conducting any station revisits. For stations nine and ten, the term ‘visited’ is used very loosely, for Optimist-Linear simply walked past the open station alcoves on his left and moved forward without pausing until he reached the exit sign on the wall facing him at the end of the hall. Optimist-Linear viewed none of the boards a second time. In fact, he only made only 9 of the 40 boards readable for a first time: two boards at station one and three at station two, but only one at station three and two at station four. Most notably, Optimist-Linear made only one of the remaining 24 boards readable, resulting a total of 31 skips. This total was strikingly higher than the student average of 5.7 skips. In fact, Optimist-Linear’s rate of skipping was conspicuously higher than any of the other students’ scores: the inclusion of his skipping score more than doubled the average for all nine students, as when Optimist-Linear’s score is excluded from the calculation, the student average for skips drops from 5.7 to only 2.5 skips. This high ratio of skipped content is important to note with regard to future study, as it can be expected to have worked in direct opposition to Optimist-Linear’s retention of information during the task.

In addition, the viewing sequence used by Optimist-Linear was somewhat scattered. For the first two stations, he started out at the first board (1A and 2A, respectively) and worked his way from left to right (1D, and 2B, 2C, respectively) in what could be considered a ‘logical’ reading sequence that parallels the way that written English is typically processed. However, this logical system was then promptly abandoned: at station three, Optimist-Linear skipped 3A and read only 3B before skipping 3C and 3D. At station four, he skipped 4A and 4B, reading only 4C and 4D. At the only other station in which he made a board readable, he skipped 8A and 8B, reading only 8C before skipping 8D. Characteristics of the Optimist profile include a high perception of spatial skill but a low demonstration of it. These characteristics could help to explain the pattern of behavior demonstrated by Optimist-Linear. He seemed to begin the task in the virtual environment with a certain amount of initial confidence, making five of eight boards readable in the first two stations and spending approximately half of his total time there. However, his scattered viewing pattern within even these first two stations seemed to indicate that this initial confidence began to peter out rather quickly as the actual requirements for navigation became more evident and – as demonstrated by Optimist-Linear's usage of secondary strategies – appear to have not been easily achieved. Indeed, by the time he reached the fifth station, his level of interaction with the environment had begun to drop significantly, resulting in the high level of skips and the essentially non-exist visits to the last two stations (as discussed above).

Although each individual board's featured text and accompanying photos could be taken as stand-alone information, with no one board necessarily dependent on another for comprehension, each set of four boards (A/B/C/D) was intended to offer a measure of cohesiveness with regard to the subject content of the information presented thereon, with each board building in sequence on the previous board (see Figure 3 to view Board 1, along with Figure 4 to view Board 10). As such, Optimist-Linear's scattered approach to interacting with the information may hold implications for his capacity to put context around the information that he did encounter.

Also of note is that Optimist-Linear resolved only four blockages, which put him well below the student average of 13.6 resolutions and left him with the lowest number of resolutions amongst the entire group. He also failed to resolve another four blockages. However, Optimist-Linear also incurred no complex blockages, which tied him with Classic-Linear for the lowest rate of complex blockages amongst the students. Optimist-Linear's navigational strategy resulted in a total of eight blockages during the virtual environment task., the lowest number of total blockages amongst the students, and well below the group average of 21.2 blockages. Optimist-Linear also bypassed 48 opportunities to interact with content on a readable board, effected two incidences of multiplication, and conducted two pivots, all of which were highly comparable to the rates demonstrated by the rest of his cohort.

However, a glaring caveat must be acknowledged when assessing many of the frequencies related to Optimist-Linear's performance in the virtual environment, especially when looking at those frequencies relative to his peers. For example, a total of 48 bypasses is unremarkable at first glance, as this rate is almost perfectly on par with the group average of 48.6 bypasses. However, the group average (excluding Optimist-Linear's overly high rate) for skipping is 2.5 skips amongst 40 boards, thereby leaving 37.5 boards as viewed. Optimist-Linear, however, skipped 31 of the 40 boards, leaving only nine as viewed. When these viewing and bypass frequencies are taken in combination, a completely different picture of Optimist-Linear's performance emerges. For the rest of the cohort, the bypass rate (48.8) as compared to the number of boards viewed (37.5) results in an average of 1.3 bypasses per viewed board. For Optimist-Linear, on the other hand, the bypass rate (48) as compared to the number of boards viewed (nine) results in an average of 5.3 bypasses per viewed board, which is more than 400% the rate of his peers.

The same calculation can be applied to contextualize other aspects of Optimist-Linear's behavior in the virtual environment. For example, a total of eight incurred blockages appears to be a very strong performance when compared to the group average of 21.2 incurred blockages. However, a comparison of Optimist-Linear's eight blockages with his nine viewed boards results in an average of 0.89 blockages incurred per board. His peers, however, had 21.2 blockages compared to 37.5 viewed boards, resulting in an average of only 0.56 blockages per board. These results indicate that, despite committing 62% fewer blockages than the group average, in reality, Optimist-Linear was actually 63% more likely to incur a blockage than his peers.

A similar process of calculation can be applied to pivoting and multiplication, if the relative number of station visits are used. Optimist-Linear made boards readable in only five of the ten stations, while ten is the group average for the number of stations in which boards were made readable. This ratio has potential implications with regard to the availability of opportunities to effect multiplication or pivoting, both of which act on multiple boards. Optimist-Linear's rate of two pivots seems low when compared to the 250% higher group average of five pivots. However, when comparative calculations are applied, Optimist-Linear demonstrates a 40% likelihood of pivoting, while the group average (a 50% likelihood) is only 25% higher. The same holds true for incidences of effecting multiplication. At two incidences, Optimist-Linear's rate is significantly exceeded by the group average of 4.8, a difference of 240%. However, when comparative calculations are applied, Optimist-Linear demonstrates a 40% likelihood of effecting multiplication, while the group average (a 48% likelihood) is only 20% higher. Although he still demonstrates rates that are lower than the rest of his cohort, looking at these differences though the lens of relative calculations allows for a truer picture of their import.

Taken together, Optimist-Linear's high rates of incurred blockage and bypassing suggest that he demonstrated less finesse at navigating his avatar into advantageous positions in front of the information boards than did his peers. His lower rates of pivoting and multiplication, both of which require camera manipulation to capture opportunities that make boards readable without requiring additional avatar movement, suggest that Optimist-Linear also demonstrated less finesse with regard to using the tools available to him within the environment. These challenges hold the potential to interfere with Optimist-Linear's ability to interact with the textual information (less so with pictures, which are more resistant to the effects of blockage and bypassing) on the boards. Characteristics of the Optimist profile include low video-gaming and social media experience, along with a high perception of spatial skill but a low demonstration of it. This profile seems to match the pattern of behavior evidenced by Optimist-Linear. A low level of demonstrated spatial skill could precipitate a lack of finesse in navigating the environment, while a lack of computer experience could account for having a lower level of finesse in recognizing the available tools (a common requirement of video games) and utilizing them (a necessary ability for navigating social media platforms) within the virtual environment.

Case Two: Gamer-Linear. This case study explores the behavior of the only video-recorded participant who fell with the *gamer* student profile. He was assigned to the linear spatial condition, where he started at station one and travelled forward until station ten, have conducted no station revisits. The viewing sequence employed by Gamer-Linear was somewhat scattered, with starting points (1C, 2B, 3C, 4B, 5B, 6B, 7C, 8C, 9A, 10A) that varied and did not appear to demonstrate the eventual formation of a consistent pattern, as might be expected during the process of becoming familiar with the layout of the virtual environment. The progression within stations was similarly varied, during which Gamer-Linear viewed eight boards a second time.

However, Gamer-Linear's sequence of starting points did appear to be consistent in its inconsistency, with strategies appearing to be tested for a short period of time before being abandoned in favor of attempting a new approach. The characteristics of the Gamer profile include a high level of video game experience coupled with a strong level of balance between perceived and demonstrated spatial skills. This level of familiarity with video games, along with a balanced perspective of his own spatial skill, may have sanctioned both an initial and a sustained confidence in Gamer-Linear's navigation of the virtual environment, allowing him to continue attempting new approaches in the ongoing effort to optimize navigation of the environment.

Gamer-Linear's navigational strategy resulted in a total of 28 blockages during the virtual environment task. Of particular note, is that he did not resolve eight blockages, which was the highest rate of unresolved blockages amongst the students and may have impacted his ability to interact effectively with information on those boards. However, using only the technique of panning, Gamer-Linear did resolve 16 other blockages. This resulted in a 2:1 ratio of resolved to unresolved blockages, to which can be added four more complex blockages that were resolved by shifting the position of Gamer-Linear's avatar. As such, it seems that Gamer-Linear likely possessed the capacity to transform the eight unresolved blockages into complex or resolved ones. The fact that they were left unresolved raises the possibility that the justified self-assurance which is characteristic of the Gamer profile may include a level of comfort with ambiguity that is unique to Gamers. As such, Gamer-Linear may have assessed the amount of blocked text on the board, together with the contextual information contained in the surrounding, readable text, and decided to test the viability of moving forward in the task with the information already at hand. Gamer-Linear also skipped three boards, putting his skip rate slightly above the group average (when Optimist-Linear's skip rate is removed from the calculation) of 2.5 skips.

Despite the high level of video game experience characterizing the Gamer profile, Gamer-Liner did not appear to manage his camera navigation significantly better than the other participants in the video-recorded sample. At 45 bypasses, Gamer-Linear's prevalence of bypassing content on a readable board was only slightly less than the group average, and his rate of pivoting, at five pivots, exactly matched the group average. However, he did effect seven incidences of multiplication, which was somewhat higher than the group average of 4.8 incurred multiplications, and may indicate quite a strong level of proficiency in avatar navigation.

Case Three: Classic-Clustered-1. This case study explores the behavior of one of the two participants in the videotaped subsample who fell with the *classic* student profile and also participated in the clustered spatial condition. One of the definitive characteristics of the Classic profile is a high level of demonstrated spatial skill, although paired with a somewhat lower level of perceived spatial skill. A high level of spatial skill did appear to factor into the approach taken by Classic-Clustered-1, as he navigated the unanticipated arrangement of each cluster in a methodical manner that ensured complete coverage of all ten stations, regardless of whether they belonged to a cluster of one, two, or three stations. He was one of only three participants in the video-recorded sample to revisit a station, both starting and finishing at station nine and visiting each cluster – and each station within each cluster – in a systematic, clockwise rotation of the circular foyer. He skipped only two of the boards, which was slightly below the group average of 2.5 skips, and viewed eight of the boards twice. The viewing sequence employed by Classic-Clustered-1 appeared to be highly organized from the start, employing a left-to-right traditional English reading sequence that started at board A for every station but one (in which board A was skipped) and also concluding with station D in nine of the ten stations. Classic-Clustered-1 also bypassed only 16 opportunities to interact with content on a readable board, which was by far the lowest rate amongst the group (who averaged 48.8 bypasses) despite the very low levels of video game experience which characterized the Classic profile.

Classic-clustered-1 conducted only one pivot, which was considerably lower than the group average of five. This shortfall may be due to the particularly low levels of computer navigation (video game and social media) experience which are characteristic of the Classic profile. Classic-Cluster-1 did not resolve five of the blockages that he encountered in the virtual environment task; however, he did resolve 17 other blockages through panning alone, along with one complex blockage that required him to adjust the position of the avatar in order to make the text on the board readable. Overall, Classic-Cluster-1's navigational strategy resulted in a total of 23 blockages during the virtual environment task, with a high ratio (3.6:1) of resolved to unresolved blockages. In addition, Classic-Cluster-1 effected five incidences of multiplication, which was slightly higher than the group average. These frequencies likely indicate that Classic-Cluster-1 could have resolved all of the blockages that occurred during his completion of the virtual environment task, but may have chosen not do so.

Case Four: Achiever-Random. This case study explores the behavior of the only participant who was a part of the video-recorded subsample and fell within the *achiever* student profile. He was assigned to the random spatial condition, which he navigated by starting at station one and travelling counter-clockwise through the virtual environment, moving sequentially through each station and ending at station ten without having conducted revisits to any of the stations. In the first station, Achiever-Random viewed the boards in a methodical manner that incurred no need for a board to be viewed a second time, but was not necessarily efficient. He started at the middle-left of the two boards (board B), then moved to the middle-right (board C), then back to the far left (board A) before finishing with the far right (board D). However, by the second station, Achiever-Random had refined his viewing strategy to employ a left-to-right, traditional English-reading approach that started at board A, then moved to B, then C, and finished with board D. Once established, the same strategy was applied identically to every station thereafter. Achiever-Random did not skip any of the boards, which caused him to stand apart from the rest of his cohort, who skipped an average of 5.7 boards. Nor did he view any of the boards a second time, thereby incurring another perceptible difference from his peers, who double-viewed a board an average of 4.8 times. Taken together, the immediacy of an efficient viewing strategy, combined with the lack of re-viewing or skipping, indicates a high level of effectiveness with regard to navigation of the information task. This demonstrated proficiency may be indicative of the elevated level of demonstrated spatial skill that is characteristic of the Achiever profile.

Also of particular note is that Achiever-Random conducted 17 pivots (termed the 'gold standard' in virtual environment navigation for the current study), which was the highest number of pivots amongst the group, and much higher than the group average of five pivots. This exceptional number of pivots – denoting a high level of finesse with regard to both avatar navigation and panning the camera effectively – may be indicative of the high level of video game experience that is characteristic of the Achiever profile. Although Achiever-Random did not resolve three of the blockages that occurred, he did resolve ten other blockages via panning alone, and was able to relocate his avatar in order to resolve two complex blockages. Achiever-Random's navigational strategy resulted in a relatively low total of 15 blockages during the virtual environment task, with a high ratio (4:1) of resolved blockages to unresolved. However, Achiever-Random demonstrated fairly average performance in other behaviors related to camera usage, bypassing 46 opportunities to interact with content on a readable board (only slightly less than the group average of 48.8), and effecting only two incidences of multiplication (noticeably lower than the group average of 4.8).

Case Five: Optimist-Random. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *optimist* student profile and also participated in the random spatial condition. Optimist-Random started at station ten and travelled clockwise, moving through each station in descending sequence and finishing with station one, not having conducted any station revisits. The viewing sequence that Optimist-Random employed within the stations was inconstant, oftentimes starting with board A, but other times – seemingly at random – starting with board C. There was some consistency within this pattern, as Optimist-Random always started with the left side (board A or board C) of a pair of boards. However, he did not always go on from there to employ the traditional, left-to-right English-reading sequence. Instead, Optimist-Random occasionally – again, seemingly at random – used a more inefficient system of switching back and forth between boards. He also viewed nine of the boards a second time, which was the highest number of double-views amongst the sample and almost double the group average of 4.8 re-views. This high rate of re-views added to the perception that Optimist-Random was 'playing things by ear' and working without a navigational plan. In addition, he skipped four boards, exceeding the group average. One of the distinctive characteristics of the Optimist profile is the pairing of a high level of perceived spatial skill with a low level of demonstrated spatial skill; this combination may contribute to a false sense of confidence that may have prompted Optimist-Random to act first, and then attempt to figure out his navigational plan 'on the fly' afterward.

Although Optimist-Random left four blockages unresolved, it is of particular note that he resolved 21 other blockages: the highest rate of blockage resolution though panning, alone, amongst his cohort. However, at eight complex blockages, Optimist-Random also tied with Classic-Random for the highest rate of blockages that had to be resolved by changing the avatar's position, a rate which was notably higher than the group average of 3.6. Optimist-Random's navigational strategy resulted in a grand total of 33 blockages (out of 40 boards) during the virtual environment task, indicating a noticeable level of difficulty when navigating the avatar into an optimal position in front of the information boards. Further affirming this apparent difficulty with avatar navigation, it is also noticeable that, at only two pivots, Optimist-Random also conducted considerably fewer pivots than the average of five pivots conducted by the rest of his cohort.

Although Optimist-Random seemed to evidence a certain amount of finesse when adjusting the camera angle to resolve blockages through panning – a demonstration of technical skill that might typically be associated with high video game experience, which is not a characteristic of the Optimist profile – he did not seem to sustain this level of performance in other tasks requiring the same type of skill set. Optimist-Random bypassed 57 opportunities to interact with content on a readable board, which was a somewhat higher number than the group average. He also effected only four incidences of multiplication, which was slightly lower than the group average.

Case Six: Classic-Clustered-2. This case study explores the behavior of one of the two participants in the video-recorded subsample who fell with the *classic* student profile and also participated in the clustered spatial condition. One of the definitive characteristics of the Classic profile is a high level of demonstrated spatial skill paired with a somewhat lower level of perceived spatial skill, along with low levels of video game and social media experience. As such, it should be considered that the Classic profile's characteristically low level of computer experience – particularly video game experience – may have been a confounding factor which interfered with Classic-Clustered-2's effective navigation of the virtual environment.

A high level of spatial skill did appear to factor into the approach taken by Classic-Clustered-2, as he navigated the unpredictability of the clustered condition – in which he did not know what the spatial layout would be until he actually entered each cluster – in a methodical manner that ensured complete coverage of all ten stations, regardless of whether they belonged to a cluster of one, two, or three stations. He was one of only three participants in the video-recorded sample to revisit a station, both starting and finishing at station one and visiting each cluster – and each station within each cluster – in a systematic, counter-clockwise rotation of the circular foyer. In somewhat of an opposite demonstration of his capability, Classic-Clustered-2 conducted only three pivots, which was considerably lower than the group average of five pivots. However, it is possible that this number of pivots may be related more to a difficulty with camera manipulation than avatar navigation.

Classic-Clustered-2 initially employed a board navigation sequence that was somewhat counter-intuitive. He started on the right (with board D) and then worked 'backwards' toward the left, which is opposite to the traditional left-to-right English-reading sequence. Classic-Clustered-2 sustained this approach for the first three stations, but seemed to be somewhat disoriented by his own strategy: although starting at board D in each station, Classic-Clustered-2 then changed the sequence of visitation for the remaining three boards each time. At the fourth station, he changed tack and started with board B, but then reverted to board D and ended up skipping both A and C. From that point forward, Classic-Clustered-2 went with a more traditional left-to-right approach and navigated the rest of the stations by starting with board A, although for his second board he still seemed to waffle between boards B and C. He also went back and viewed six of the boards a second time. Along the way, Classic-Clustered-2 also skipped four boards, a rate of skipping that was higher than the group average.

Of particular note is that Classic-Clustered-2 bypassed 90 opportunities to interact with a readable board, which was by far the highest rate of bypassing amongst the entire sample and nearly double the group average of 48.8 bypasses. This pattern of difficulty with managing the camera is indicative of the characteristically low level of video game experience typified in the Classic profile. However, at nine incidences of multiplication – also a behavior that could be associated with video game skills – Classic-Clustered-2 effected the highest rate amongst his entire cohort. In addition, he resolved 20 blockages through panning alone.

Classic-Clustered-2 left seven blockages unresolved, but he did resolve 20 other blockages thorough panning and incurred seven other (complex) blockages which required changing the avatar's position to resolve them, resulting in a high ratio (3.9:1) of resolved to unresolved blockages. Classic-Clustered-2's navigational strategy resulted in a grand total of 34 blockages (out of 40 boards) during the virtual environment task, which was the highest total number of blockages amongst the group and indicates a noticeable level of difficulty when navigating the avatar into an optimal position in front of the information boards.

Given the above observations, Classic-Clustered-2's behavior is somewhat of a paradox. On the one hand, when navigating the virtual environment as a whole, he seems to evidence the cohesive set of spatial skills that would likely be anticipated from a member of the Classic profile. On the other hand, however, when navigating the information boards within each station, he seemed to find it more difficult to develop a cohesive strategy. In similar vein, he achieved elevated rates of multiplication and blockage resolution, two behavioral strategies that appear to be strongly associated with a high level of finesse in manipulating the camera. Yet, he also demonstrated an extreme level of bypassing, a strategy which appears to be associated with difficulty in manipulating the camera. As such, in future research it would be worth taking a closer look at the underlying skill sets – and their interaction with the environment – to gain a better understanding of their contribution to the deployment of these behavioral strategies.

Case Seven: Classic-Random. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *classic* student profile and also participated in the random spatial condition. Classic-Random was the only participant who, after being ‘dropped’ into the circular foyer of the random spatial condition, began navigating the virtual environment at a station which was not positioned directly next to the sign with the exit directions. He was also one of only three of the video-recorded participants to revisit a station. Upon entering the museum, Classic-Random crossed the foyer to begin at station four. From that point, he travelled counter-clockwise and moved through four more stations before briefly peering back into station four (without entering), and then revisiting station five. During this process, Classic-Random appeared to have no consistent strategy for interacting with the information boards within each station. He employed a different start point and visitation sequence each time, and revisited a number of boards. He was also the only participant amongst his entire cohort who did not conduct any pivots at all during his navigation of the boards. However, once he seemed to have ‘gotten his bearings’ within the larger environment, Classic-Random seemed to settle on a consistent strategy (e.g. starting with board A each time) for navigating the smaller environment of each station. During this process Classic-Random also skipped four boards, which was higher than the group average, but effected eight incidences of multiplication, which was also higher than the group average.

Of particular note is that Classic-Random incurred eight complex blockages that required movement of the avatar in order to resolve, a number which tied Classic-Random with Optimist-Random for the highest number of complex blockages amongst the sample. One of the characteristics of the Classic profile is low video game experience, a skill set which includes camera manipulation. This low skill level may account for the high rate of blockages which

Classic-Random did not resolve through panning. Classic-Random also incurred three unresolved blockages, which required relocating the avatar in order to reveal the blocked text. However, he did resolve 14 blockages solely through panning. His navigational strategy resulted in a total of 25 blockages during the virtual environment task, which was only slightly higher than the group average. In addition, Classic-Random bypassed 52 opportunities to interact with content on a readable board, a number which was also only slightly higher than the group average. Overall, despite the Classic profile's characteristically low levels of computer experience and perceived spatial skill, Classic-Random seems to have been able to use his high level of demonstrated paper-and-pen spatial skill to hold his own.

Case Eight: Classic-Linear. This case study explores the behavior of the only participant from the videotaped subsample to fall within the *classic* student profile and also participate in the linear spatial condition. Classic-Linear started at station one and travelled forward, moving through each station sequentially and ending at station ten without conducting any station revisits. Classic-Linear navigated the information boards in a largely methodical manner, using the same start point in eight of the ten stations but varying the sequence of the remaining three boards, and viewing three of the boards a second time. He skipped only two boards, which is slightly lower than the group average. A high level of demonstrated spatial skill is characteristic of the Classic profile, which may account for Classic-Linear's apparent confidence in navigating the virtual environment despite also having the lowest technical (video game and social media) experience amongst the four student profiles.

Of particular note is that Classic-Linear incurred no complex blockages that required moving the avatar to reveal the blocked text, tying with Optimist-Linear for the lowest number of complex blockages amongst their cohort. This absence of complex blockages indicates that

Classic-Linear demonstrated a measure of competency with navigation of the avatar when positioning it in front of the information boards. Classic-Linear did leave six blockages unresolved, but also resolved eleven other blockages using only panning. Classic Linear's navigational strategy resulted in a total of 17 blockages during the virtual environment task, which was comfortably lower than the group average of 21.2 blockages.

Classic-Linear bypassed 44 opportunities to interact with content on a readable board, which was slightly lower than the group average. He also effected three incidences of multiplication (which was lower than the group average of 4.8 incurred multiplications) but conducted seven pivots, which was somewhat higher than the group average of 5 pivots. Taken together, these behaviors indicate that, despite the Classic profile's characteristic low video game experience, Classic-Linear appeared to be able to hold his own when navigating the virtual environment and manipulating the camera.

Case Nine: Optimist-Clustered. This case study explores the behavior of the only participant from the videotaped subsample who fell within the *optimist* student profile and also participated in the clustered spatial condition. Optimist-Clustered navigated the virtual environment in a manner that seemed to rely on well-proven methods of navigation: he started at station nine (immediately to the right of the exit sign) and then travelled clockwise, moving through each cluster and ending at station one without revisiting any stations. He employed a consistent viewing pattern from the beginning, starting at board A in every station and then moving from left-to-right in a typical reading sequence until finishing with board D. This sequence was disrupted only twice, once when the readability of a board was sustained for less than three seconds, and once when Optimist-Clustered briefly made a board readable for a second time. It is notable that along the way, the positioning of his avatar effected multiplication just once, resulting in the lowest number of multiplication instances amongst his entire cohort. This may indicate that Optimist-Clustered did not have a broad awareness of his environment and was quite target-focused, thereby not realizing what was happening with other boards other than the one immediately in front of him. However, he bypassed only 42 opportunities to interact with content on a readable board, which was somewhat less than the group average of 48.8 bypasses.

Optimist-Clustered left only one blockage unresolved, which was the lowest number of unresolved blockages amongst his cohort. Optimist-Clustered incurred two complex blockages which required repositioning the avatar in order to reveal the blocked text, and he was able to resolve nine other blockages using only panning. Although his blockage resolution rate is noticeably lower than the group average of 13.6 resolutions, Optimist-Clustered's navigational strategy resulted in a total of only 12 blockages during the entire virtual environment task, which was substantially lower than the group average of 21.2 and only slightly higher than the lowest rate of eight blockages, as demonstrated by Optimist-Linear.

Optimist-Clustered's total blockage rate becomes even more noteworthy when comparative calculations (see *Case One: Optimist-Linear*) are applied to Optimist-Linear's record-setting rate of eight total blockages. Optimist-Clustered demonstrated a rate of 0.31 total blockages per viewed board, while after applying the comparative calculation, Optimist-Linear actually effected a much higher (287% higher, in fact) rate of 0.89 total blockages per viewed board. As such, it could be considered that Optimist-Clustered achieved the lowest rate of total blockages amongst the entire group of students.

When looking only at the statistics, the pattern of Optimist-Clustered's use of secondary strategies appears to be different than what might be expected, given the characteristics of his profile membership. For example, it is characteristic of the Optimist profile to have low video game and social media experience, which might logically be expressed as a relatively low level of finesse with regard to moving an avatar through a virtual environment and using camera manipulation. However, Optimist-Clustered's numbers don't seem to support this circumstance and, at first glance, it appears that (in defiance of his profile characteristics) Optimist-Clustered seemed to be quite skilled at both avatar navigation and camera manipulation. This is evidenced by the fact that he conducted 12 pivots, which was more than twice the group average of five pivots. However, taking a step back from the numbers to look at the overall pattern of Optimist-Clustered's behavior introduces the possibility of an entirely different perspective.

For example, when viewed through the lens of caution, as opposed to skill, the different parts of Optimist-Clustered's behavior start to suggest a different context for his actions. Although he seemed to make few 'errors' (e.g. blockages) during his navigation of the virtual environment, he also took very few risks. Rather than testing theories and exploring possibilities, Optimist-Linear used only what might be viewed as 'tried-and-true', low risk methods of navigation (clockwise direction, sequential visitation, left-to-right interaction), both in the larger environment and within the smaller stations, and he seemed limit his focus to only one thing at a time rather than being aware of his larger environment. In addition, his relatively low rate of bypasses may have indicated a somewhat cautious approach to camera manipulation, while the possibility exists that his record-breaking rate of blockage avoidance could be attributed to an equally cautious approach to avatar manipulation. Hence, although the numbers remain the same, the implications for future engagement in a virtual environment task are quite different. The presence of skill suggests a level of confidence that could be leveraged toward future engagement, while the presence of caution may suggest less inclination to pursue further involvement, along with less ability to reap the what have been suggested as some of the main benefits of learning in virtual environments such as exploration, discovery, and 'learning by doing' (Hanewald, 2013, p. 240).

Summary of case study analysis. It is clear that the study of learner behavior during an information-based task that takes place within a virtual environment has only begun. Indeed, these case studies have primarily affirmed that each learner is a highly unique individual who is prone to act in unpredictable ways. Though patterns of behavior associated with profile membership are certainly present, they are lived out in different ways depending on the environment (in this case, the spatial condition). Therefore, although the information gleaned from this study is a valuable contribution to the literature in itself, it should also function as somewhat of a springboard to launch further investigation of the interaction between the variables of learner profile and learning environment.

Discussion Part III: Integration of Cases

Over three decades ago, Thorndyke and Hayes-Roth (1982) pointed out that, with repeated experience, individuals increase the accuracy of their knowledge about a particular environment. The authors' position appears to have stood the test of time, for it provides a salient explanation for some of the participants' behavioral changes over time – and across spatial conditions – during the current study. It is important to note that some participants demonstrated evidence of learning about their environment by changing their behavior – termed below as *economizing* – during the course of their tenure in the virtual environment. Although other participants may also have learned about their environment, they did not demonstrate the behavioural change that would have helped to provide evidence of that learning. Rather, it appeared as though some participants discovered a comfortable status quo and then 'capped' their process of learning about the environment at that point in time, choosing to ‘stay the course’ with what had already been learned and remain constant for the remainder of the task.

Economizing. Thorndyke and Hayes-Roth (1982) discuss the concept of *procedural knowledge* (p. 562) which encodes information such as landmarks and the amount of space between different points along a route, and is derived directly from the personal experience gained by navigating a particular route. This growth of procedural knowledge appeared to occur for several of the participants in the current study, resulting in observable changes with regard to how they interacted with the virtual environment during the course of the task. For the purpose of the current study, this evolution of strategy is considered to define the concept of *economizing*, which is then further delineated into *positive economizing* and *negative economizing*.

In the current study, just prior to their entry into the virtual museum, participants were provided with written instruction via an instruction board on the wall that read, “In the next task, you will be presented with a number of museum displays. Please read all material very carefully and try to remember as much as you can”. This instruction board ‘clued participants in’ to an understanding that the objective of the upcoming task was information retention. Upon entry to the virtual museum, participants who engaged in positive economizing began developing an evolving strategy that might save them time or effort, but which could still be anticipated to contribute toward the effectiveness of meeting the objective of the information task. Participants who engaged in negative economizing began developing an evolving strategy that might save them time or effort, but which could be anticipated to detract from the effectiveness of meeting the objective of the information task.

Negative economizing. Nowhere is a better example of negative economizing found than with Optimist-Linear. Initially taking the time to interact with both the text (verbal content) and the pictures (nonverbal content) on the information boards, Optimist-Linear spent approximately half of his virtual environment journey on navigation of the first two stations, during which he viewed two boards in the first station and three boards in the second. This proved to be the apex of his engagement with the written text, however. He quickly seemed to reach the conclusion that he could change his approach in order to scoot through subsequent stations more quickly. He still viewed two boards in each of the next two stations, but more expediently. By station five, he was not staying long enough to make the text on the boards readable, which indicated that he was interacting only with the nonverbal information (pictures). At station eight, he lingered long enough to make one board readable, but upon re-entering the hall, simply ditched the last two stations altogether. He strode down the hall so decisively that not even a picture had time to catch his eye, heading straight to the ‘get me out of here’ button on the wall at the end of the hall.

Positive economizing. There are a number of examples of how participants engaged in positive economizing, but the most striking was effected by another member of the Optimist profile: Optimist-Clustered. In order to most effectively explain how this occurred, time will be expressed as a percentage of Optimist-Clustered’s total time spent in the virtual environment. Optimist-Clustered seemed to start out with what could be considered a ‘default’ plan of action that was heavily based on traditional navigation methods, and required little or no innovation. He travelled clockwise through the clusters, without going backward at any time to revisit a station, and used a consistent viewing pattern that always started at board A on the far left and then moved to the right in a typical reading sequence until reaching board D. Optimist-Clustered seemed to consider his movements within the virtual environment carefully, and to focus on completing the task without necessarily ‘experiencing’ the task. This pattern was true with regard to his use of almost all of the secondary strategies. However, about 12% of the way into his journey through the virtual environment, Optimist-Clustered discovered the ability to pivot. It was at that ‘pivotal’ point that something changed. Whether the first pivot occurred by design or was simply a happy accident is unknown, but at 23% of the way through his journey, Optimist-Clustered pivoted again. And then again at only 30%. And from that point forward, Optimist-Clustered got increasingly more efficient at entering each station, positioning himself in an optimum spot, and then pivoting between information boards in a way that effectively minimized the need for avatar navigation within the station. Although some variation occurred between subsequent pivots, by the time he concluded his twelfth pivot (a ratio of more than one pivot per information station) and prepared to exit the virtual environment, Optimist-Clustered had made 39 of the 40 boards readable, and in a stellar demonstration of positive economizing, had whittled his time between pivots down to only 3%.

The role of avatar representation in economizing. All participant avatars in the current study took the form of a young male adult, not dissimilar to the average age of an undergraduate student. The avatar was in perpetual motion, so that even when his actual momentum was halted, he appeared to rock back and forth slightly as though primed for further movement. This perpetual motion is a standard feature of the Unreal Engine game development platform used to develop the virtual environment conditions for this study, and it helps avatars to appear more lifelike. In their study of how avatar appearances affect behavior within virtual environments, Lam and Riedl (2011) found that avatar representation significantly impacted the behavior of the individual controlling the avatar, so much so that the virtual identity represented by the avatar superseded a participant’s real-world identity.

This finding raises the question of whether the 'primed for action' representation of the avatar in the current study may have induced greater likelihood for participants to experience a sense of impatience to move forward and "get on with" the sequence of tasks in the virtual museum. If so, the frequency of impulse-prone, negative economizing behaviours such as bypassing and skipping may have been encouraged to increase, while the more ponderous, positive economizing behaviors such as pivoting and blockage resolutions may have been somewhat pre-empted. As an element of future study on the optimization of virtual environments for learning, it would be helpful to study the impact of modifying the body language of avatars – with some avatars 'urging' action and others 'urging' thought – in order to establish whether this differentiation affects the behavior of learners.

The potential impact of learning style on economizing. Ramirez-Correa, et al. (2017) studied the impact of students' individual learning styles on the benefit that students received from their interaction with learning technology, specifically a learning management system. Learning styles "define" (Ramirez-Correa, 2017, p. 273) a student's strengths, and impact their preferences with regard to receiving, and comprehending novel information (Felder & Silverman, 1998, in Cheng, 2014). These information processing preferences then serve to establish a student's manner of learning (Ramirez-Correa, 2017). The nature of a student's learning style affects their engagement with technology; for example, the type of visual learning styles preferred by a student was found to impact their satisfaction with technology (Ramirez-Correa, 2017). In a study of the relationship between students' learning styles and their perceptions of the efficacy of learning within the *Second Life* virtual environment, Cheng (2014) found that significantly more active than reflective learners found the virtual environment experience to be useful and satisfying, while significantly more verbal than visual learners were satisfied with the communication aspects of the learning experience. In summary, if a technology-based learning opportunity could be customized to match the learning style of a particular individual, both the attitude toward the learning task and the student's perceived satisfaction level with their experience could be anticipated to demonstrate an increase (Cheng, 2014).

It is important to note, here, that learning styles have been the subject of over 40 years of extensive study that has featured much debate, and little consensus (Li, Medwell, Wray, Wang, & Liu, 2016). Lack of clear definition, inconsistent reliability and validity, and disagreement about specific characteristics are all sources of contention (Curry, 1990, in Li, et al., 2016). Franklin (2006) spoke strongly against the employment of learning styles, stating that there were "major problems" (Franklin, 2006, p. 82) with applying learning styles in education and suggesting that "labelling" (p. 86) students belied important contextual considerations. Willingham (2012, in Li, et al., 2016) agreed, declaring outright that the well-known categories of verbal, auditory, and kinesthetic (VAK) learning styles "[did] not exist" (p. 90).

Given the above uncertainty with regard to the validity of learning styles, it is suggested that appropriate caution be considered if asking whether the learning styles of participants in the current study may have made an impact on the nature of their economizing behavior when navigating the virtual environment. In retrospect, it becomes evident that the current study carried a certain amount of presumption that participants would learn primarily through a verbal medium – reading – which has traditionally been the go-to information delivery system in education. Although differences between preferences for verbal or visual learning could be somewhat muted by the fact that the current study did not incorporate communication between avatars – either human or agent – during the virtual environment task, the distinction between the two approaches to learning still carries potential implications for behavior within the current study, for Cheng (2014) also found that 81% of the participants (p. 114) in his study were visual learners and preferred to access information presented in pictures or diagrams.

All of the information boards in the current study proffered information via both text and picture data, but only the text-based data's accessibility was entirely dependent on making the board readable. However, the possibility exists that a learner who prefers pictures to text may be less conscientious about making the text on the boards readable. This possibility raises the question of whether such a learner could have developed at least a rudimentary understanding of the information on the boards simply by viewing the pictures and not concerning themselves with making the text readable. Were this to be the case, participants' preferred method of information presentation may present a possible confounding variable when assessing behavior within the virtual environment. Depending on whether progress has been made toward consensus in the area of learning styles, future research on similar tasks within a virtual environment may want to consider including a measure of participants' preference for visual versus verbal presentation of information in order to look at controlling for this potential variable.

Spatial condition. Yanez-Gomez, Cascado-Caballero, and Sevillano, et al. (2017) defined the "usability" (p. 5759) of a learning platform as relating to its *playability*, *effectiveness*, and *efficiency*, whereby "effectiveness is the capability to produce a desired result, whereas efficiency is the ability to produce the result while minimizing the effort" (p. 5757), and playability relates to the satisfaction level of the user. Hanewald (2013) iterated that the element of *fun* that learners experience while engaged in a task within a virtual environment has a significant impact on their corresponding level of favorable reception to the tasks, themselves. For example, *serious games* are purposeful video games designed to be used as a platform for training or educational purposes (Barata, Gama, & Jorge, 2016, Yanez-Gomez, et al., 2017). Although it may seem like being concerned with the level of 'fun' in a 'serious' game is somewhat of an oxymoron, the usability – including the enjoyment level – of the learning platform does make a powerful impact on its efficacy, as the final determination of a serious game's effectiveness is the effort expended by the individual who is engaged in it (Barata, et al., 2016, Yanez-Gomez, 2017), and that level of effort is certainly affected by a learning platform's usability.

Taking into account the above information, it is helpful to evaluate the usability levels of each of the three spatial conditions according to the definitions given by Yanaz, et al., (2017). However, some interesting challenges present themselves with regard to doing so within the structure of the current study. Efficiency is a hallmark of design, and is therefore relatively easy to evaluate for each spatial condition from the perspective of the designer's thought process and intent. Effectiveness is the capability to produce a desired result. Given the focus of the current study, one logical definition of desired result would be the prevalence of positive and negative economizing behaviors. The subsample size – three video-recorded participants per condition – was too small to conduct a valid quantitative analysis. As such, the initial qualitative case study analysis (detailed in the *Results* section, *Case Studies* subsection, along with the *Discussion Part II: Qualitative Analyses* section, *Second Research Question: Case Studies* subsection) will serve as the indicator of effectiveness for the current study. The behavioral microanalysis revealed that behaviors related to both positive and negative economizing occurred across all three spatial conditions. Therefore, for the current study, a similar level of effectiveness will be considered to have been established for all spatial conditions. Playability, the third element of usability, is the satisfaction level of the participants. Participants in the current study were not directly asked about their level of satisfaction, so non-verbal information will be substituted in the absence of verbal information. Therefore, playability will be largely inferred by the behavior of individual participants.

Linear condition. Of the three spatial conditions, the linear condition provided the highest level of directed navigation to participants. The linear condition was designed for maximum efficiency, featuring ten stations arranged down a long hallway in a sequential order that began with station one and finished with station ten. Upon entering the virtual museum, participants were 'dropped' directly into station one, after which they had the freedom to move up and down the hallway at will. While each station had to capacity to function as a "stand alone" source of information, there was also a corporate element to the sequence of information delivery that provided a certain amount of scaffolding which started in station one and completed in station ten (see Figures 4 and 5 to view the information content of stations one and ten). Each station in the linear condition branched off from the left side of a single hallway that curved slightly to the left, preventing participants from seeing the end point of the hall until reaching the tenth station. The intent of this curvature was twofold: to encourage continual engagement via an obvious progression, but without making the 'end' obvious from the beginning; and to provide a certain amount of fidelity with the random and clustered spatial conditions, which take place in a virtual museum featuring a circular foyer. At the end of the linear condition's single hallway, a sign facing the participant provided instructions on how to exit the museum.

When viewed through the lens of establishing the level of playability (satisfaction) associated with each spatial condition, the behavior of the three video-recorded participants assigned to the linear condition was quite informative. The linear condition hosted a Classic, an Optimist, and a Gamer, providing a well-rounded set of viewpoints. Classic navigated the sequential stations of the linear condition in a largely methodical manner. He used the same start point in eight of the ten stations, but slightly varied his approach to the other boards. He skipped only two boards, and made a second look possible for three of the boards. Classic did not seem to change his approach much throughout the entire task, indicating a level of comfort with the layout and a perspective of, "if it ain't broke, don't fix it". Given the pattern of Classic's consistent approach to navigation and completion of the information task, it seems likely that he was satisfied with his experience in the linear condition.

Optimist, on the other hand, definitely seemed to perceive that the linear condition was 'broken'. Although it would seem that Optimist's characteristic low levels of video game experience and spatial skill would make the straightforward layout of the linear condition a good fit for him, this did not seem to be the case. Based on behavioral observation, it seemed that Optimist experienced a very low level of satisfaction in the linear condition. He made boards readable in only five of the ten stations, resulting in an extremely high level of skips. Although he seemed to give the first few stations "the old college try", by the fifth station he had ceased to make any of the boards readable. After the eighth station Optimist dropped all pretense of engagement and simply walked straight down the hall at a determined pace until he found the exit sign and was able to spring himself free. Given the progressive pattern of Optimist's behavior during his participation in the linear condition, it is likely that his satisfaction level with the linear condition was extremely low.

Gamer completed all tasks in the linear condition, albeit in what initially appeared to be somewhat of a scattered fashion. Upon closer inspection, however, it seemed that Gamer's sequence of starting points appeared to be consistent in their inconsistency. Indeed, it appeared as though his trip down the never-changing hallway of the linear condition prompted him to "stir things up a bit" by testing different strategies along the way. This restlessness indicates a relatively low level of satisfaction with the linear condition. It appeared that, in order to keep himself on task, Gamer had to find a way to introduce some sort of novelty or challenge into the environment. That, for Gamer, the predictable linear condition would prove uninspiring is unsurprising. Given the very high level of video game experience characteristic of his profile membership, it is likely that Gamer experiences an enjoyment of the problems, puzzles, and peculiarities which are often motivational drivers for playing video games, and which were intentionally absent from the linear condition. Given the likelihood that Gamer seemed to feel the need to introduce a level of novelty to his completion of the task, it is likely that his satisfaction with the linear condition as a stand-alone experience was low.

In summary, it may initially seem logical that the linear condition was the most facilitative for learning because it required the least navigational effort on the part of the participant and presented information in a pre-determined logical and sequential manner, thereby preserving cognitive resources and making them available for information retention. However, given the response of the above participants, it may be the case that these 'labor-saving' attributes are actually creating unintentional barriers to engagement. However, further study should be conducted to determine whether this pattern holds true for a larger sample.

Random condition. The random condition was designed to provide the lowest level of directed navigation to participants, while still offering the option of efficiency. It featured the same ten stations as the linear condition, but arranged in sequential order around a circular foyer that began with station one and finished with station ten. Stations one and ten were positioned to the left and right sides (respectively) of a sign that provided exit instructions. In similar format to the linear condition, each station had the capacity to function as a "stand alone" source of information, but there was also a corporate element to the sequence of information delivery that provided a certain amount of scaffolding which started in station one and continued until station ten (see Figures 4 and 5 to view the information content of stations one and ten). Each station in the random condition was designed as an ‘alcove’ that led off from the circular foyer, and participants were free to enter any station at will. In a similar design to that of the linear condition, the entrance to each alcove was open. However, in the random condition, a wall was positioned just inside each entrance to block the participant’s view of the alcove’s contents until after the participant navigated their avatar around the wall and into the station, itself.

The behavior of the three video-recorded participants assigned to the random condition was quite informative with regard to the level of satisfaction that they seemed to experience. The random condition hosted an Achiever, an Optimist, and a Classic, providing a well-rounded set of viewpoints. Achiever seemed to find the random condition to be user-friendly. He took advantage of the sequential layout, navigating it counter-clockwise and visiting all stations in sequence without a single deviation. He seemed confident that he had covered all contingencies, and did not seem to experience the need to double-check his bearings by revisiting a station. Although he seemed a bit disorganized during his interaction with the boards in the first station, by the second station he seemed to have ‘caught the rhythm’, transferring the systematic approach facilitated outside the stations to the information boards inside the stations. Like his external strategy, once established, Achiever’s internal strategy was identically applied to every station and he did not make a single board readable a second time. Overall, Achiever’s behavior was highly consistent throughout the task, indicating that he did not seem to experience boredom, frustration, or discouragement. As such, it appeared that Achiever was satisfied with the random condition.

Optimist conducted his external navigation of the random condition in much the same way as Achiever, visiting the stations in a sequential order that brooked no exceptions and no revisits. However, that is where the similarity ended. Optimist travelled clockwise, starting at station ten and visiting the stations in descending order, and his internal navigation of the information boards was radically different than Achiever's. Optimist's viewing sequence for the information boards was inconsistent and highly inefficient, as he often moved back and forth between the pairs (A/B and C/D) of board. He bypassed 57 readability opportunities, and ended up viewing nine of the boards a second time, which was the highest number of re-views amongst the sample and almost double the group average of 4.8. In addition, he skipped four of the information boards altogether. It seemed that, unlike Achiever, Optimist was unable to convert his systematic external plan of navigation to a comparative internal one. Adding to his scrambled internal navigation strategy, Optimist incurred eight complex blockages that required him to take the time to reposition his avatar, a rate that was much higher than the group average of 3.6, and that tied him with Classic (see below) for the record. In total, Optimist ended up having to deal with a blockage at 33 of the 40 information boards, resulting in what was very likely a frustratingly high rate of 83%. Although it is characteristic of the Optimist profile to have low levels of video game experience and demonstrated spatial skill, the stark contrast between Optimist's very predictable navigation of the external environment and his equally scrambled navigation of the internal environment begs further inquiry as to the possibility it may not be Optimist's inherent characteristics, alone, that caused him to struggle. Rather, the fact that Optimist was subject to the information boards in reverse order should be taken into account. Overall, Optimist's behavior suggests that his level of satisfaction with the random condition is likely to be low.

Classic was the only video-recorded participant to begin his external navigation of the random condition in what appeared to be a truly random fashion, beginning his exploration of the virtual environment at station four, which was not positioned directly next to the exit sign and required Classic to cross the foyer to reach it. This eventually proved to be a highly inefficient approach. Classic's internal strategy for navigating station four seemed very scattered. He started at board D, then moved back and forth across the station, viewing board C once, A and D twice, and B three times. He then stopped in at station five and viewed board B, after which he seemed to scrap his original strategy and start over. He headed back to station one and proceeded sequentially from there, revisiting stations four and five along the way. Although he viewed only two of four boards in station one, once Classic had established a consistent external strategy he seemed to be able to develop a parallel consistency for his internal strategy (e.g. starting with board A each time). However, after revisiting stations four and five, Classic seemed to lose his 'flow' somewhat and he skipped two of the four boards in station six. However, he seemed to recover, and he returned to his consistent viewing pattern. Given the overall discombobulation that Classic seemed to experience during times that he seemed unsure of his bearings within the virtual museum, it is likely that his satisfaction level with the random condition was low.

In summary, it appeared that there was a direct correlation between the how the three video-recorded participants interacted with the random condition's external sequence of stations, and their level of efficiency when interacting with the information boards contained within each station. This finding may hold ramifications for the effectiveness of the random condition as a delivery vehicle for learning activities. Further investigation to establish whether this pattern holds for a larger sample should be conducted.

Clustered condition. The clustered condition was designed to provide a moderate level of directed navigation to participants. Making use of the same type of circular foyer as the random condition, the clustered condition featured the same ten stations as the other two spatial conditions, but they were grouped into five clusters that held one ('single'), two ('double'), or three ('triple') stations. Each station had the capacity to function as a "stand alone" source of information; however, the stations within the clusters were grouped using content association to facilitate maximum information retention. As was true for the stations in the other conditions, the clusters were scaffolded from I – V because of a corporate element to the sequence of information delivery. Cluster I held station one, cluster II held stations 2, 3, and 7, cluster III held station 8, cluster IV held stations 4, 5, and 6, and cluster V held stations 9 and 10. Each cluster was designed as an 'alcove' that led off from the circular foyer, and participants were free to enter any cluster at will. The entrance to each alcove was open, with a wall positioned just inside each entrance to block the participant's view of the alcove's contents until after the participant navigated their avatar around the wall and into the cluster, itself. The entrances to clusters I and V were positioned to the left and right (respectively) of a sign that provided exit instructions.

The clustered condition hosted two Classics and one Optimist, providing an opportunity to compare the satisfaction levels of two members of the same student profile within the same spatial condition. Classic-1 navigated the unanticipated content of each cluster in a systematic, clockwise rotation of the foyer that both started and finished at station nine and ensured complete coverage of all ten stations, regardless of their cluster association. Right from the beginning, Classic-1 seemed to have the capacity to institute a highly organized, left-to-right (A through D) viewing strategy. He skipped only two of the boards, and viewed eight boards twice. Most significantly, Classic-1 committed only 16 bypasses, which was one-third of the sample mean

(M=48.8). Despite the Classic profile's characteristically low level of video game experience, it seemed that the profile's characteristically high level of pen-and-paper spatial skill was enough to facilitate Classic-1's effective navigation of the clustered environment. He seemed to find the external environment of the clustered condition unintimidating. With only five alcove entrances to initially choose from, Classic-1 seemed to find it relatively simple to develop an effective external strategy for navigating the foyer, and then easily transform it into an effective internal strategy for interacting with the information boards. Based on his consistent pattern of behavior, absent of any aberrations that might indicate frustration or discouragement, it is likely that Classic-1 experienced a high level of satisfaction with the clustered spatial condition.

Classic-2 also navigated the unpredictability of the clustered condition in a methodical manner that ensured complete coverage of all ten stations, regardless of their cluster membership. Classic-2 started and finished at station one, visiting each cluster – and each station within each cluster – in a systematic, counter-clockwise rotation of the foyer. In cluster I (a single that held only station one), Classic-2 employed a board navigation sequence that was somewhat counter-intuitive, starting on the right (board D) and then working toward the left in a pattern opposite to the traditional left-to-right manner of interacting with the English language. Classic-2 continued to use this approach in cluster II, which resulted in two re-views at station two, one skip at station three, and two more skips at station four. Classic-2 moved on to cluster III and, in the uncomplicated environment of a single station, seemed to reset his approach. Starting now at board A in each station, Classic-2 seemed to encounter difficulty again when navigating cluster IV's three stations. He managed the first station well, but skipped one board in the middle station and required two re-views in the last station. In addition (and in direct contrast to Classic-1), Classic-2 bypassed 90 opportunities to interact with a readable board, which was the highest rate of bypassing amongst the sample and nearly double the group average of 48.8. Given that Classic-2 seemed to do well at navigating the external structure of the clustered environment, but then to struggle (and potentially experience some discouragement) when presented with more than two information stations in the same cluster, it would seem that he had a mixed experience – likely accompanied by a mediocre level of satisfaction – in the clustered condition.

Optimist navigated the clustered condition in a manner that seemed to rely from the start on well-proven methods of navigation. Like Classic-1, he started at station nine and travelled clockwise through all of the clusters, but unlike both of his Classic counterparts, he did not revisit his first station at the end of his circuit. With his external strategy well in hand, Optimist immediately instituted an internal strategy for navigating the information boards. He went with another well-proven method and used a left-to-right approach that always started at board A and ended at board D. With the exception of 42 bypasses and one skip, both of which were well below the group average, Optimist continued this approach without interruption and appeared to complete the task effectively. Based on the level of competence that Optimist seemed to display throughout his navigation of the clustered condition, and the absence of any behaviors that might indicate frustration or discouragement, it seems likely that he was satisfied with his experience in the clustered condition.

In summary, it seems that all three of the video-recorded participants who completed the information task in the clustered condition appeared to have at least some positive experiences. Even for Classic-2, who seemed to struggle with clusters containing more than two stations, the overall layout of the clustered condition seemed to facilitate the early formation of an effective strategy that all three participants were able to carry forward for the duration of the task. In addition, for at least two of the participants, this strong external strategy seemed to facilitate the formation of an effective internal strategy that, in turn, could allow for optimum interaction with – and retention of – the information contained on the boards. However, future investigation should be conducted to determine whether this apparent result holds true for a larger sample.

Moderate constructivism, spatial condition, and economizing. When a *weak reading* (Percival, 2000) of moderate constructivism is applied to the observation and analysis of participant behavior, there are possible applications with regard to differences between the initial and subsequent behaviors of participants. For example, when looking at the impact of the learning environment – as altered by spatial condition – on participants' use of primary and secondary strategies (see *Method* and *Results* sections), a suggestion could be made that participants' "interpretations" (Stecker, 1997, p. 44) made an impact on the attributes or *usability* (see *Discussion, Part III* section, *Spatial Condition* subsection) of the particular spatial condition to which they were assigned, thereby contributing to the development of positive or negative economizing.

The current study sought to analyze behavior based on the stability of student profile and the static component of spatial condition. Stecker's (1997) theory of moderate constructivism suggests the possibility that these two variables may carry an interactive effect, whereby profile characteristics may have contributed to participant interpretations and impacted the use of secondary strategies within a particular spatial condition. Future research – in which larger and more equivalent sample sizes are available for both variables – should investigate the possibility of an interaction between participant profile and spatial condition.

Problem solving. Problem-solving is a universal learning task that undergirds the acquisition of knowledge. When learners encounter earlier problems, the process of solving those problems can provide the opportunity to develop strategies that will allow learners to more easily solve later problems (Gee, 2005a). In the case of the starting points for the random and clustered spatial conditions, participants were 'dropped' into the center of a circular foyer, from which a number of identical openings radiated. As such, in order to begin their mandated task, participants were immediately faced with the need to solve an imminent problem – where to start, how to transverse the foyer, and which opening to enter first – for which they had to devise and execute an initial strategy. This imminent problem was not present for learners in the linear condition, however, who were simply 'dropped' into the first station as their starting point.

The difference made by the presence of an imminent problem is something worth investigating in future research, for the facilitation of experiential learning ("learning by doing", Hanewald, 2013, p. 240), whereby learners form their own ideas and then test those ideas against the possibilities, is a key component of effective learning opportunities within a virtual environment (Hanewald, 2013). In the current study, the linear spatial condition offered little obvious opportunity for the construction and/or testing of personal theses about the function of the virtual environment. However, in the random and spatial conditions, it became clear very quickly that participants needed to make some sort of assumption – some form of initial "hypothesis" (Hanewald, 2013, p. 240) – about the layout and function of the environment, after which there was nothing to do but jump in, test their idea, and then decide if the test proved or disproved their initial assessment. For example, in Case Seven: Classic-Random's situation, whose initial 'hypothesis' appeared to be tested by travelling across the foyer and entering a seemingly-randomly-chosen station, the first hypothesis appeared not to survive the initial test. Instead, it appeared that a second hypothesis (e.g. Use the exit sign as a starting point and then travel sequentially through clusters/stations from that point onward), was born, put to a new test, and affirmed.

In addition, Gee (2013b) points out that people are motivated when facing situations that feel “challenging but doable” (p. 29) and provide “pleasantly frustrat[ing]” (Gee, 2005a, p. 36) problems that are within – but at the outer limits of – an individual’s ability to resolve. Juul (2011) suggests that navigation within and around rules is the most common source of enjoyment and satisfaction for players of a game. As rules are often the greatest source of ‘problems’ – and subsequent frustration – for players in a game, these two ideas are quite complementary. When looking at the current study’s three spatial conditions through the lens of opportunity to experience ‘pleasant frustration’ (Gee, 2005a, p, 36) the possibility arises that the two conditions which are most likely to encourage intrinsic motivation may be the random and clustered conditions, simply because they required participants to develop a primary strategy in order to navigate the environment.

The concept of ‘pleasant’ frustration (Gee, 2005a, p. 36) relates to a study by Richardson, et al. (1999), who found that participants’ ability to navigate a simpler, single-floor virtual representation of a building was predictive of their ability to navigate the same floor in the real thing, but participants had considerably more difficulty with multi-floor navigation. In a related finding, Ruddle, Payne, and Jones (1998) studied participants who navigated through a single-floor virtual building, after which they were asked to identify the direction in which their starting point lay. The authors found that if participants had navigated a simpler path containing only one or two turns, they demonstrated a much higher level of accuracy than if they had navigated three turns (Ruddle, et al., 1998). These studies demonstrate that there can be a fine line between what is consistently achievable, and what moves beyond the achievable level to become frustrating.

Indeed, observation of the six participants in the random and clustered conditions appears to indicate that four of them experienced a certain amount of satisfaction during completion of the information task. For these participants, it appears that – although both pleasantness and frustration were present – the experience was more pleasant than frustrating. For the other two participants in the random and clustered conditions, it the frustration level seemed to outweigh the pleasantness, resulting in a decrease in, or absence of, satisfaction.

Landmarks. Waller, et al. (1998) discussed the process involved in developing an understanding of how to navigate a space, including the stages involved in developing a mental representation of an environment. The authors point out that the first stage of this process involves paying attention to landmarks, but without having an understanding of how those landmarks relate to each other or to the environment as a whole. The spatial conditions in the current study have distinct differences with regard to the presence of landmarks, particularly with regard to their initial presence and location. Rand, Creem-Regehr, and Thompson (2015) posit that individuals do not "automatically encode" (p. 650) information about their spatial environments, but must make a conscious decision to notice and remember spatial information. Therefore, it would logically follow that the saliency of information in a virtual environment is likely to have an impact on how easily that information is noticed and remembered. For example, in the linear condition, there were no evident landmarks that allowed participants to 'get their bearings' within the virtual environment, or to get a sense of the task that they were expected to complete. This may have contributed to the considerable frustration level that Case One: Optimist-Linear seemed to experience during his navigation of the linear condition, likely resulting in the highly effective use of negative economizing which he employed during completion of the information task.

However, in the random and clustered conditions, a sign on the wall of the circular foyer was easily spotted at the beginning of the task. Although this sign provided exit instructions to be followed after completion of the task, all of the videos gave evidence that participants used the sign as a landmark to assist them in navigating the virtual environment. For example, although all of the alcove (station) entrances that opened from the foyer were identical in appearance, five of the six participants chose to begin by entering the station either immediately to the left or to the right of the sign, and then continued either clockwise or counter-clockwise around the foyer until arriving back at the sign. Case Seven: Classic-Random initially chose an entrance several removed from the sign, but soon appeared to ‘start over’ by abruptly breaking his initial visitation sequence, moving directly to the station directly beside the sign, and continuing station by station from that point onward.

The significance of landmarks is important with regard to future research on the optimum development of virtual environments as learning environments. For example, Li and Gleitman (2002) present the concepts of *allocentric* referencing (orienting by situating oneself according to a perspective centred externally to the individual, thereby referencing such concepts as “east” or “north”) and *egocentric* referencing (orienting by situating other things according to a perspective centred internally to the individual, thereby referencing such concepts as “right” or “left”). The authors note that the type of linguistic patterning within the language spoken by an individual has an impact on what sort of strategy they will naturally use to – quite literally – ‘get their bearings’ when orienting themselves within an environment. For example, if the individual’s spoken language contains exclusively allocentric terms, the spatial concepts associated with egocentric terms will not be a part of the individual’s repertoire when devising and/or deploying navigational strategies (Li & Gleitman, 2002).

Although the current study used a convenient sample of post-secondary students from a large university with a considerable population of international students, demographic information was not collected with regard to participants' preferred languages. This should be a consideration for future study so that the implications of allocentric or egocentric referencing can be further investigated. The implications for the configuration of virtual environments designed for broad-scale learning (e.g. for multicultural or global audiences, or for institutions with international student populations) are significant and should be explored, as accommodating a variety of learners may require providing a variety of "landmark cues" (Gleitman & Li, 2002, p. 280) within the virtual environment to meet both allocentric and egocentric criteria.

Rules inherent to spatial condition. Salen (2007) points out that players of video games are not only discoverers of the rules that govern gameplay, but also experimenters who test the boundaries of those rules and then use the results of those tests to determine their next moves within the game. This concept can also be applied to spatial navigation of a virtual environment, for while the win/lose ludus rules (see *Literature Review* section, *Video games* subsection) as discussed by Ang, et al. (2008) are often specific to games, the paidea rules of environmental design (see *Literature Review* section, *Video games* subsection) are much broader in nature and the testing of environmental boundaries within the virtual environment may hold some interesting implications with regard to the learning that takes place within it.

Although learning outcomes related to the retention of information board content were not assessed for the purposes of the current study, it is nevertheless enlightening to look at the evidence of participants' exploration of the paidea rules of the virtual environments. For example, Case Four: Achiever-Random appeared to engage in a process of trial and error to determine the most effective way to navigate the random condition, while Case Two: Gamer-

Linear appeared to engage in a process of experimentation to increase his enjoyment of the linear condition. Case One: Optimist-Linear definitely tested the rules of the virtual environment, finally discovering that he could take control of his own experience and remove himself from the environment entirely. In fact, almost all of the subsample of participants evidenced engagement in the process of testing the paidea rules of their assigned spatial condition, and then determining how to use what they had learned to develop their next course of action.

In addition, Wallet, et al. (2013) found in their study of active navigation within a virtual environment that spatial knowledge was more easily acquired when participants were engaged in active physical navigation (Wilson, Foreman, Gillett, & Stanton, 1997) of the virtual environment from an egocentric perspective that was facilitated by being in a ground-level mode (Wallet, et al., 2013), as opposed to simply playing the role of a passive observer of the events (and environmental elements) that were encountered during the task. The authors found that, although both the ‘active’ and ‘passive’ participants received the same amount of egocentric ground-level exposure to the virtual environment, the participant who was required to actively make spatial decisions about how to navigate the environment increased their retention of the occurrences within the environment (Wallet, et al., 2013).

All of the participants in the current study navigated their virtual environments from a ground-level egocentric perspective, as opposed to navigating from an aerial viewpoint that would have facilitated an allocentric perspective. Wallet, et al.’s (2013) finding begs the question of whether the participants in the current study who navigated the random or clustered environments – requiring active navigational decisions to be made about where to begin the task, which route to take moving forward, and how to end the task – were at a cognitive advantage over their linear counterparts because of the inherent activation of the random/clustered participants' active engagement in the virtual environment task. This question would need to be answered using a larger sample size for whom content retention learning outcomes had been assessed, and as such, is a question for future investigation.

Event chains. Holmes and Gee (2016) discussed the difference between engaging students in a "chain" of learning activities – whereby the completion of one activity leads to discovery of the next – versus providing students with a composite that 'gives away' the entire scope of all learning activities at once. A common practice in video games, the continual presentation of new challenges upon completion of old ones is one of the elements that give these games their ongoing appeal, and the conclusion of Holmes and Gee (2016) was that the presentation of individual learning events was more likely to be effective than the common practice of laying all of the pending learning activities out in advance. In constructing a virtual environment for the purpose of engaging students in learning, the spatial configuration can be modified to provide students with a series of individual learning events that can engender curiosity and anticipation, rather than an overview of the future that initially stimulates interest but fails to sustain it. The question is then raised: can spatial configuration be considered as a learning support?

This concept of an event chain is embodied in the three spatial conditions used for the current study. Certain types of information presentation (e.g. maps, photos, verbal directions) trigger different cognitive processing procedures, and depending on the type of *integration* that is required to make sense of the relationships between various spatial locations, this differentiation results in a diversity of judgments (Thorndyke & Hayes-Roth, 1982, Uttal, Fisher, & Taylor, 2006). For example, the linear spatial condition utilized in the current study presents spatial information about the virtual environment in a sequential, *serial* manner, which makes it more difficult for the participant to infer judgement about the overall nature of the environment (Uttal, et al., 2006).

As such, the possibility arises that the linear condition may stimulate an initial interest in the virtual environment, but as the participant moves through the seemingly-endless continual progression of identically laid out information stations, that initial interest in the learning environment may taper off and the overall engagement of the learner may be subject to apathy. This possibility is borne out by the observation that the participant (Case One: Optimist-Linear) to skip the most information boards (31 of 40 boards) was navigating the linear condition, and the rate at which the participant skipped boards increased with their progression through the virtual environment. By the time Optimist-Linear interacted with the last two stations – at which point the end point of the condition was finally in sight – he stopped making any pretense of effort with regard to reading the information, instead simply walking past the two stations on his way to exit the virtual environment.

In the random condition, however, information about the overall nature of the environment was provided up front, allowing participants to begin making decisions in a more *simultaneous* manner (Uttal, et al., 2006). Although the learning events were also identical in nature and the end point was known from the beginning, participants had the freedom to make some autonomous decisions about how they preferred to experience the learning events.

Conversely, although the end point was also known from the beginning in the clustered condition and participants again had the freedom to choose how they navigated the series of learning events, each event carried an unknown component related to the number of stations (one, two, or three per cluster) that would be a part of that event. Choice naturally breeds novelty, as each decision that must be made is a novel decision. By this stipulation, the virtual environment spatial condition which offered the least novelty was the linear condition, while the greatest novelty was within the clustered condition and the random condition was left somewhere in the middle. As novelty helps to stimulate human interest and cognitive engagement, future study should examine whether the level of environmental novelty in a virtual environment may influence a user's subsequent level of effort when engaging with informational material.

Ang, et al. (2008) speak to the idea that, according to the theory of cognitive constructionism, rules are learned by engaging in a cycle of hypothesis testing and reflection; the problems that need solving may be either explicit (e.g. the problem is obvious) or implicit (e.g. the problem must be figured out), while the solutions to the problem are virtually always implicit (Ang, et al., 2008). This leads each individual to construct their own perspective about what the rules mean and how they can be applied to solve the identified problems. However, in observing the ways that the video-recorded participants navigated the different spatial conditions of the virtual environment, it became evident that the paidea rules of the virtual environment could also be considered as "tools" (Gee, 2008, p. 234).

For example, the way that participants chose to engage in economizing (see *Discussion, Part III* section, *Economizing, Negative economizing,* and *Positive economizing* subsections) was directly related to how they discovered and implemented those paidea rules. Additionally, most participants discovered the opportunity provided by multiplication – a paidea rule native to all three virtual environment conditions – and used it to minimize the amount of avatar movement required to make the boards readable. Other participants may have triggered a multiplication opportunity as they navigated the virtual environment, but they did not seem to notice it or did not consider it to be an asset. With practice, some participants became increasingly adept at entering a new station and quickly identifying an opportunity for multiplication, thus economizing the amount of time and effort needed to interact with the information on the boards in the station and, ultimately, in the entire virtual environment. Pivoting was an example of another paidea rule that participants could use as a tool for economizing. By making a second board readable with little or no extra effort other than that which had already been expended to make an initial board readable, participants could engage with the text in the virtual environment in a much more expedient manner. For the purposes of this study, taking advantage of multiplication or pivoting falls within the category of positive economizing (see *Positive Economizing* subsection).

Conversely, some participants discovered other paidea rules that allowed them to economize in a completely different way. Bypassing and skipping were options within the virtual environment that participants could use to cut down on their effort, but taking advantage of these paidea rules pre-empted the participant's opportunity to engage with readable text on the boards and thus potentially reduced or removed their opportunity to interact with the associated information. For the purposes of the current study, taking advantage of these paidea rules falls with the classification of negative economizing (see *Discussion, Part III*, *Negative Economizing* subsection).

Limitations of the Current Study

Sample size. One important limitation to this study is sample size. Although the sample of 133 participants that was used for the student profiles was of a robust size, the size of the subsample was very small at only nine participants. It is recommended that further investigation of participant behavior in a virtual environment be conducted utilizing a larger sample to increase the generalizability of the results.

Convenient sample. The participants for this study were a convenient sample of 133 undergraduate psychology students at a Canadian university, making the results generalizable primarily to other post-secondary students who are studying psychology. As such, although the current sample is of a reasonable size, it remains a very small fraction of the post-secondary student population. Although it is important to note the results of this analysis, further study should be conducted in order to replicate these results on a larger scale across multiple institutions, and preferably across multiple countries.

In addition, it is important to look at whether data collected from post-secondary students is generalizable to other populations. Although Rozin (2010) makes the point that first or second year university students represent only 0.2% of the world's population (p. 108) and are therefore a very poor representation of the social processes of human beings, he also states that undergraduates still offer a strong representation of humanity's "basic psychological processes, such as learning" (p. 108). Rozin (2010) goes on to say that these same individuals, despite their notable differences from most of the world's current population, are also "a vision of the future" (p. 109) and that studying them is an effective way to begin to develop an understanding of the world's future population. As such, although it is important to note the results of this analysis, further study should be conducted in order to replicate these results on a larger scale and across institutions.

Use of keyboards versus game controllers. Game controllers were not made available to participants in the current study. Instead, avatar navigation of the virtual environment during the information task was accomplished by pressing the four arrow keys (up, down, left, right) on the laptop keyboards. As it is the case that many – if not most – individuals who regularly play video games typically use a game controller to navigate an avatar within a virtual environment, it is important to note that the use of the keyboard for navigation may have hampered the navigational ability of individuals who are accustomed to game controller usage. It is recommended that future study provide opportunity for both game controller and keyboard use in order to assess the impact of navigational tools on participant employment of secondary strategies.

Premeasures. Because this study was conducted using a convenient sample of participants recruited from the participant pool at the University of Alberta, a limitation of sixty minutes was placed upon the amount of time allotted for each research trial. As such, decisions regarding pre- and post-measures were heavily prioritized and administration time was tightly controlled. During the course of this study, it has become apparent that a number of other pre-measures would have been helpful in providing a more comprehensive understanding of participants. As such, the current study is limited by the lack of information collected with regard to participants' learning styles (e.g. visual versus verbal), personality styles or temperaments (e.g. conscientiousness), or demographics (e.g. preferred language or language of origin).

Absence of social interaction. One of the important benefits often mentioned in the literature when discussing the use of virtual environments as a platform for learning are the presence of low-risk, high potential opportunities for social interaction and collaboration (Bronack, et al., 2006, Chang, et al., 2009, Hanewald, 2013, Hew & Cheung, 2010). In addition, a meta-analysis of learning in virtual environments revealed that two of the three primary cognitive skills most commonly acquired were engagement and communication (Reisoglu, et al., 2017). The current study did not provide opportunity for participants to interact with other human-avatars (or computer-controlled agent-avatars) during their completion of the task in the virtual environment. As such, there is a host of questions about the potential impact that such collaboration may have had on the prevalence of target behaviors and the use of economizing. In addition, if the fledgling theory of moderate constructivism is to be considered as a possible context for this study, so should be the possibility that social interaction may have changed participants' interaction with the virtual environment and altered their perception of its nature As such, it is suggested that future research investigate the impact of completing an information-based task in a virtual environment within the context of social interaction, preferably with both human-avatars and agent-avatars.

Researcher interpretation. It is one of the premises of qualitative research that researcher self-reflection, along with recognition of the presence of interpretation, are important acknowledgments when establishing the validity of a qualitative study (Creswell, 2015). Given the nature of the quantitative cluster and qualitative case study formats of statistical analysis that were used within this study – and the level of researcher influence with regard to key decisions within those processes – it is important to acknowledge that the researcher/author of this study carried several anticipations. For example, the coding of behaviors and the development of the protocol for the subsample analysis proved to be an exercise that required self-reflection on the part of the researcher, who soon realized that it was difficult to abstain from attributing intent to a participant's behavior (e.g. which board a participant was 'trying to read'; whether he could 'guess' what was behind a small amount of blocked text on a readable board; etc.). As such, the author/researcher realized the need to decrease subjectivity by creating highly defined criteria (e.g. the "entire" board must be in "clear" focus) that ensured consistent data collection across participants.

Self-reflection also revealed the anticipation that the student profiles with high levels of video game experience (e.g. the Gamers and the Achievers) would have a proportionately large membership amongst the sample. It was also anticipated that individuals with high levels of video game experience would be more likely to navigate the environment/information boards in an efficient manner. In addition, it was expected that they would be more adept at managing their avatars and manipulating the camera than those with lower levels of experience, thereby incurring less bypasses and skips, while engaging in more pivots and multiplication. However, the data did not bring these anticipations to bear, delivering instead – in the true spirit of exploratory research – a somewhat different discovery.

Conclusion

Two primary research objectives guided the course of this study. The first research objective was to investigate and define the presence of homogenous profiles within a sample of undergraduate students with regard to their computer experience and spatial abilities. This objective was operationalized through the following research question: “Does undergraduate students’ prior exposure to three elements of computer usage – software awareness, video game experience, and social media usage – in combination with their perceived and demonstrated spatial skills, allow for the classification of students into stable groupings which can then function as student profiles?” In response to this question, a cluster analysis was conducted on the data of 133 undergraduate students, revealing four clusters with unique combinations of characteristics related to spatial skill and computer experience. In direct contrast to what was expected given the prevalence of student technology use as documented in the literature, the student profile with the largest membership had low rates of technology use, while the two highest rates of technology use were attributed to the two clusters with the smallest memberships, totaling only 29% of the sample between them.

The second research objective guiding this study was the intent to conduct an in-depth observation and investigation of individual student behavior representing different student profiles and occurring within diverse virtual environment spatial conditions. The research question operationalizing this objective was, “Can in-depth exploration of the nature and frequency of identified undergraduate student behaviors, in combination with student profile membership and virtual environment spatial configuration, yield insight into the likelihood of behavioral occurrences during an information-based learning task that takes place in a virtual environment?” Secondary research questions involved underlying implications as identified in relevant literature, and potential directions for future research. To answer this question, case studies were conducted on the behavioral data collected and coded from the nine video-recorded participants from the original sample of 133 undergraduate students.

When putting together the ‘whole picture’ of this study, it became apparent that the different virtual environment spatial conditions acted as somewhat of a petri dish within which to observe a variety of learning dynamics and different behaviors, while the four student profiles offered a platform from which to generate a number of additional questions and ideas.

For example, initially it seemed logical that the linear condition would best facilitate learning because it required the least extraneous effort and therefore preserved cognitive resources for the information task. However, results of the case study demonstrated that the reduced cognitive workload may have actually created barriers to engagement with the information task, rather than removing them. In contrast, the higher cognitive load embedded within the clustered condition seemed to ‘kick-start’ participants’ cognitive processes and, by requiring the formation of an effective navigational strategy, also facilitated the formation of an effective strategy for optimum interaction with the information contained on the boards.

It is also important to note that the clearest examples of positive and negative economizing (see *Discussion, Part III* section, *Negative Economizing* and *Positive Economizing* subsections) were both demonstrated by members of the same student profile. Taken together with the fact that all strategies inherent to economizing were employed within all three spatial conditions, it would seem that neither form of economizing is more likely to occur within a specific spatial condition or amongst members of a particular profile. This raises questions that should be the subject of future study which employs a larger sample size to investigate the possibility of an interaction effect between student profile and spatial condition.

Highly detailed analysis, such as the one conducted for the current study, is extremely time- and resource-intensive, making it prohibitive to conduct this type of in-depth investigation for large sample sizes. Therefore, despite the difficulty in generalizing the results of a small sample to the larger population, it remains important to glean as much value from the available observations as possible. As such, this study makes an important contribution to the literature regarding the use of virtual environments as platforms for learning, and the results of the cluster analysis and case studies do not engender apathy.

This study's findings regarding the characteristics and membership of student profiles serve to challenge commonly-held assumptions about the nature of student populations in large metropolitan universities. This study also provides a strong basis for generating new questions about optimizing virtual environments to encourage high quality learning experiences that allow both the learner and the instructional facilitator to experience satisfaction with the learning experience and associated outcomes. Much like the clustered condition's need for navigational strategy seemed to jumpstart students' cognitive processes, the findings of the current study's cluster analysis and case studies now function to 'boot up' another round of research questions.

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