Abstract: New virtual reality (VR) applications for education appear frequently but rarely contain explicit pedagogies. Educational leaders need the pedagogies to support teaching and learning strategies and optimize student learning. A theoretical model (Kebritchi & Hirumi, 2008) aided in analyzing visual and text based content and distinguishing unstated pedagogies in VR applications. The research question was: What principles and practices of pedagogy are evident but not articulated in selected VR applications for education? A total of 35 VR applications met the selection criteria. Analysis of public content for the VR applications showed most were experiential while others categorized as discovery learning, constructivism, situated cognition, direct instruction or unclassified approaches. Elements of primary and secondary pedagogies were found in some applications. Educators and VR designers could use explicit pedagogical frameworks to support faculty development, construct extended and congruent curricular options that stimulate reflections, build insights, and insure innovative and measurable outcomes.
April 8, 2017,

Dear Editors

I am submitting an original research manuscript for publication consideration in Computers and Education (Exploring pedagogical foundations of existing virtual reality (VR) educational applications: A content analysis study). The authors are Elizabeth Johnston, Gerald Olivas, Patricia Steele, Cassandra Smith, and Liston Bailey who are affiliated with Center of Educational and Instructional Technology Research (CEITR) University of Phoenix.

We believe this manuscript is appropriate for publication in the Computers and Education Journal. We see commonality between the scope and aims of the journal and those of our study. Our goal was to use a directed content analysis design to clarify the pedagogical foundations of 35 virtual reality (VR) educational applications where pedagogies were unstated. A second goal was to test the organizational pedagogical schemata developed by Kebritchi and Hirumi (2008) as the initial set of categories that could aid in analyzing content from various public sources and distinguishing educational pedagogies in VR applications. We hope our paper builds on existing literature related to pedagogical foundations of Virtual Reality educational applications. This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose. Thank you in advance for your time and effort in considering our submission.

Respectfully yours,

Elizabeth Johnston
Senior Research Fellow
Center of Educational and Instructional Technology Research (CEITR)
University of Phoenix

Exploring pedagogical foundations of existing virtual reality (VR) educational applications: A content analysis study

Elizabeth Johnston, Gerald Olivas, Patricia Steele, Cassandra Smith, Liston Bailey,
Center for Educational and Instructional Technology Research (CEITR)

Author Note
Elizabeth Johnston, Ed.D, Senior Research Fellow (CEITR), Associate Faculty, School of Advanced Studies, University of Phoenix; 1625 W. Fountainhead Pkwy, Rm. 423 Tempe, AZ, 85282

Gerald Olivas, PhD, Associate Faculty, School of Advanced Studies, University of Phoenix; 1625 W. Fountainhead Pkwy, Rm. 423 Tempe, AZ, 85282

Patricia Steele, Ed.D, Associate Faculty, School of Advanced Studies, University of Phoenix; 1625 W. Fountainhead Pkwy, Rm. 423 Tempe, AZ, 85282

Cassandra Smith, Ed.D, Associate Faculty, School of Advanced Studies, University of Phoenix; 1625 W. Fountainhead Pkwy, Rm. 423 Tempe, AZ, 85282

Liston Bailey, PhD, Associate Faculty, School of Advanced Studies, University of Phoenix 1625 W. Fountainhead Pkwy, Rm. 423 Tempe, AZ, 85282

Correspondence concerning this research project should be addressed to
Elizabeth Johnston at ljohnston@email.phoenix.edu
Abstract

New virtual reality (VR) applications for education appear frequently but rarely contain explicit pedagogies. Educational leaders need the pedagogies to support teaching and learning strategies and optimize student learning. A theoretical model (Kebritchi & Hirumi, 2008) aided in analyzing visual and text based content and distinguishing unstated pedagogies in VR applications. The research question was: What principles and practices of pedagogy are evident but not articulated in selected VR applications for education? A total of 35 VR applications met selection criteria. Analysis of public content for the VR applications showed most were experiential while others categorized as discovery learning, constructivism, situated cognition, direct instruction, or unclassified approaches. Elements of primary and secondary pedagogies were found in some applications. Educators and VR developers could use explicit pedagogical frameworks to support faculty development, construct extended and congruent curricular options that stimulate reflections build insights and insure innovative and measurable outcomes.
1. Introduction

The value of virtual reality (VR) is clear as related to learning difficult, tedious, or dangerous tasks (Janssen, Tummel, Richert, & Isenhardt, 2016). VR educational experiences could provide an interactive learning opportunity that supports learning in an explorative, practice-based, and visually rich environment that emphasizes more engagement, accelerated learning, increased learner attention, lowers overall educational costs, can support challenged learners, works well to bypass language literacy and improves retention. Gaining critical thinking skills is possible with VR educational applications using student centered learning and collaboration. VR learners could increase theoretical understanding through experience, visualize complex models, and participate in an engaging learning environment (Friena & Mott, 2015; Chang, 2016). To take fullest advantage of VR, educational leaders need to understand the pedagogical aspects of VR applications to distinguish and support different strategies and optimize learning for students.

1.1. Rationale

Educational leaders need criteria to prepare, apply, assess, and evaluate VR applications before integrating within existing curricula (Lovequist, Shorten, & Aboulafia, 2015; Bacca, Baldiris, Fabregst, Graf, & Kinshuk, 2014; Kahai, Jestire, & Rue, 2013; Psotka, 2013). Preparation involves collaboration from national, regional, and local leadership at each level of interaction with a VR program including discussion of university level roles (Lau, 2015), the possibility of nationwide certifications (Psotka, 2013) and consideration of specific VR curriculum, assessed pedagogical relevance and ideas, challenges, discussions, recommendations, and benefits. Factors involved in preparation would include classes, equipment, classroom setting, and training (Miller, 2014). Application involves implementing, educating, and immersing students in a VR environment with clear assessment in mind. Assessment depends on pre-determined, desired goals, or outcomes and must take into account curriculum developer and teacher training. Evaluation could support and validate future changes, opportunities, challenges, or successes by setting the direction and goals for the next application.

1.2. Formulating the problem: Existing literature on specific VR applications is often oriented towards effectiveness or assessment of pre-existing learning objectives (Solak & Erdem, 2015; Glegg, Tatla & Holsti, 2014; Vincent, Sherstyuk, Burgess, & Connolly, 2008) or discussions of VR environmental aspects (von Schwerin, Richards-Rissetto, Remondino, Agugiaro, & Girardi, 2013), and the pedagogical structures of many VR educational applications are not clearly articulated (Fowler, 2015; Mikropoulos & Natsis, 2011; Ștefan, Moldoveanu, & Gheorghiu, 2016). Lacking a clear perspective about how the VR applications align to existing educational teaching and learning principles means that educational leaders may not effectively prepare, apply, assess, and evaluate VR educational applications as recommended by the literature (Kahai et al., 2013; Lovequist et al., 2015; Psotka, 2013) leading to less than optimal learning opportunities for students. A gap in the literature exists, and to insure that educators further accept
incorporating VR in more contexts, additional analytic research is needed to identify the pedagogies for evaluation and related effectiveness (Stefan et al., 2016). The research question was: What principles and practices of pedagogy are evident but not articulated in selected VR applications for education? One anticipated outcome of the research was to align descriptions, demonstrations, reviews, and other public content to characterize pedagogical foundations in educational applications where the pedagogical foundations were not explicitly articulated.

The purpose of the qualitative, directed content analysis study was to categorize visual or text content gathered from multiple public websites in analysis of VR applications for education that lack articulation of pedagogical foundations. A second purpose was to test the organizational pedagogical schemata developed by Kebritchi and Hirumi (2008) as the initial set of categories that could aid in analyzing content from various public sources and distinguishing educational pedagogies in VR applications.

Results of the directed qualitative-content analysis study could be useful to practicing educators who need a clear view about which application to use, how to apply that application within an existing or new curriculum, and how to meet desired expectations. Designers for VR applications will be interested in how leaders in the educational community will choose to assess, and evaluate VR applications for pedagogical purposes. Additionally, the results builds on existing literature (Fowler, 2015; Mikropoulos & Natsis, 2011; Ştefan, et al., 2016) and provides insight into new and improved ways of learning and teaching that may be possible through the use of virtual reality technology.

1.3. Theoretical Assumptions

Qualitative studies in particular, gain credibility from clear statements of problem, methodology, ontology, and theoretical assumptions underlying the research (Twining, 2009). Underlying theoretical assumptions are derived from the Kebritchi and Hirumi (2008) pedagogical model. The distinctions supported further discriminations of VR applications when analyzing Kolb’s model of experiential learning where feeling, observing, thinking, observing, conceptualizing, acting or experimenting were conceived as a four part cycle of learning (1984). The research team used these theoretical understandings to clarify or distinguish between experiential learning and other closely related pedagogies such as constructivism or discovery learning. The analysis was interpretive using several forms of data derived from content and aligned with the Kebritchi and Hirumi model.

The research team assumes most VR educational applications have a potential element of experiential learning present (Fowler, 2015). Learners can encounter experiential learning in real or artificial environments (Egenfeldt-Nielsen, 2005) thus VR does open possibilities for learners to experience environments that are difficult to access, dangerous, environmentally damaging, socially or culturally unacceptable, or very expensive in real life. Situated cognition and direct instruction as developed in VR
applications take place in an environment specifically constructed to facilitate the experiences. Accordingly, the research team was alert for experiential and other pedagogical principles working in tandem.

2. Method

The context for the study was the online environment where organizations describe and demonstrate their own educational VR applications and where the most recent information on VR educational applications is available. The research team leveraged content analysis approach to analyze content from public sites. Content analysis is a qualitative research method for identifying the frequency of concepts, words or themes within text (Nagai, 2015). The analysis included descriptive information on VR educational applications provided by concept creators, designers, graphic artists, development professionals, distributors, and sellers. The research included a review of reported VR experiences of the application users. Videos or other demonstrations allowed insights into how pedagogical experiences had been structured for users. Qualitative public content for VR technology includes information about various perspectives, such as the experience users could encounter, tasks users might need to perform, and the user’s demographic traits.

2.1. Population:
The population was public content used to describe VR education applications found online and published between January 1, 2014, and December 31, 2016 to insure we were reviewing current work during the time frame when a majority of all available VR educational applications were developed. The sample was restricted to VR applications developed explicitly for education. VR applications developed exclusively for games and entertainment were not included, though some game-like features existed in some applications. Cost was not a factor in determining the VR educational applications to include in the sample.

For the population of this study VR educational applications encompassed all types of VR delivery systems including 3D viewing, controlling what you see (zoom in and out and 360 degree navigation), interacting with what you see, as well as allowing for full physical and mental immersion into an environment. These delivery systems used a variety of viewing devices including goggles, displays (PCs, laptops, tablets, and mobile phones), tables, and screens.

2.2. Sampling: A purposive sampling technique, such as critical case sampling could aid in the investigation to determine if a phenomenon is worthy of investigating further before adopting a maximum variation sampling technique to pull more information pertaining to the phenomenon (Benoot, Hannes, & Bilsen, 2016). Purposive sample techniques could posit as a way for the researcher to select, use, and judge websites subjectively through a thorough assessment of the content. The search continued until a saturated sample was reached that included critical case examples for multiple
disciplines across demographic and subject matter groups.

Within this study the sampling procedures involved using a series of keywords to organize a search for content on web pages that described VR applications with the potentiality for being applied using different educational pedagogies. We used Google, YouTube and Bing to find public content about VR educational applications where they were sold, displayed, or demonstrated. We used EBSCOhost, ProQuest, and Google Scholar to search the literature for related articles. Key words for the content and literature search were Virtual Reality, Augmented Reality, Virtual Technology, Simulations, Immersive Learning, 3D learning environments, Collaborative virtual learning, Interactive Learning Environments, VR pedagogical applications, University VR educational applications. While reviewing the web content the team looked for variables of interest, such as descriptions of educational approaches or reported outcomes, delivery method (desktop or mobile) or source operating system (for e.g., iOS, and Windows Mobile). Often, the search produced unanticipated findings and team members followed these up. None of the applications were purchased or tested beyond the public information available online.

In addition, team members looked at source content or origin for the web content during the review of web pages and online content. The websites were chosen for their feature of an VR educational application and often included a YouTube video or simulation. When simulations were available, members of the research team could compare notes on the media and associated messaging. Sites that featured visual content in addition to text were selected as the additional resources provided an opportunity to bring in secondary forms of evidence as a means to triangulate findings across sources. An initial list of URLs for 57 different web pages was entered onto a spreadsheet for review and categorization. Personal desktop and laptop computers, tablets, and smartphones were used to gather existing public content from multiple websites of several organizations.

2.3. Sample: The sample was comprised of public content related to 35 VR applications and URLs developed for educational use and listed in Appendix A. The first steps in analysis consisted of checking the content for errors, duplications, and fit to the sample criteria. The research team eliminated websites that were platforms rather than applications. From the initial list of 57 URLs, 35 applications were selected for a final review and content analysis within this study. The sample content often included short videos, demonstrations, reviews, descriptions, or other forms of related content that could be used to triangulate text based analysis. Characteristics of the sample consisted of various organizations including private companies (10), public corporations, owned by one or more individuals and included for profit (22), and universities or public foundations (3). Discipline characteristics included academic subjects (13), medical (12), military (2), engineering or architectural (3), and multi-purpose (5). Content analysis codes for these organizations and disciplines are listed in Appendix C. The VR educational applications could be used in a variety of settings including pre-school, K-12, trade school, community college, university, medical, manufacturing, engineering, government, and military contexts.
2.4. The Framework for analyzing data
The research team used a theoretical model where descriptions of direct instruction, experiential learning, discovery learning, situated cognition, constructivism, and unclassified approaches were previously developed in an analysis of electronic games (Kebritchi & Hirumi, 2008), which were suitable for transfer to the present study to analyze the structures of selected VR educational applications. Content analysis key words for these categorical descriptions are listed in Appendix B.

2.5. Procedures:
Directed content analysis is a structured approach to analysis where theoretical frames drawn from existing research are used to guide the analysis (Hsiu-Fang & Shannon, 2005). The process is deductive, and research team members use existing categories to analyze content.

The team began to examine content in a directed analysis (Hsiu-Fang & Shannon, 2005) by using an existing theoretical model drawn from the literature and comparing content to existing categories (Mayring, 2000) using a set of five typologies and definitions taken from a previous study of pedagogical foundations in educational computer games (Kebritchi & Hirumi, 2008). The team used the unclassified category when content was found that did not align with any of the five categories. The deductive process allowed the research team to examine and develop inferences, while drawing on a variety of evidential sources to reach conclusions.

Using the step process (Mayring, 2000), the research team studied and analyzed text based descriptions; videos, industry reviews, and user comments of the VR applications with the intent to find inferred or implied pedagogical foundations. A matrix was constructed showing all the applications along the vertical axis and the pedagogical category with brief notes along the highest horizontal axis. The step process involved 1) defining various aspects of each theoretical pedagogy, 2) clarifying and developing examples through continuous comparisons, 3) developing a coding system within a matrix, 4) continuous cross checking with other team members, and 5) final designations of categories.

The team studied details of the Kebritchi and Hirumi model (2008) to assure an understanding of differences. The team identified and agreed on examples. A list of keywords that aligned with the existing pedagogical categories was constructed. Text based content was examined for these keywords. We grouped words similar words. For example, drill, drilled, drills, drilling, would be considered together.

In a second step, the team used videos and program descriptions that showed the pedagogical aspects of a VR educational application to draw inferences, which were compared to text based insights. However, inferences or implications were restricted to specific features within each application (Kohlbacher, 2006). Motivations or attitudes were not included in the analysis; in addition, the team did not consider potential aspects that might be developed outside of the VR application. The analysis followed an
exhaustive pattern of individual and collective reviews where coding was checked, challenged, and re-evaluated in an iterative process until the research team reached consensus. In a third round of analysis, the research team revisited applications where distinguishing predominant pedagogy had been challenging. The final round allowed team members to identify elements of secondary pedagogies, which are listed in Table 2. Continued use of the matrix allowed the team to organize and compare analysis by individual team members.

3. Results and Discussion
The next sections have been organized to answer the research question: What principles and practices of pedagogy are evident but not articulated in selected VR applications for education? Table 1 displays the research team identified VR educational applications as associated with their most prevalent pedagogical foundations; direct instruction, experiential learning, discovery learning, situated cognition, constructivism, and unclassified approaches. These pedagogical foundations are based on definitions derived from the pedagogical model developed by Kebritchi and Hirumi (2008). Recognized educational theorists were further referenced to support and expand on these definitions. Detail for each category follows.

Table 1
Pedagogical Foundations for VR Educational Applications (n = 35)

<table>
<thead>
<tr>
<th>Educational Application</th>
<th>Direct Instruction</th>
<th>Experiential Learning</th>
<th>Discovery Learning</th>
<th>Situated Cognition</th>
<th>Constructivism</th>
<th>Unclassified Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D White House Gallery VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agent Cayley Virtual Reality</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alchemy VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Altspace VR</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomage Table</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomy VR</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomyou</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apollo 11 VR Experience</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Augmented REality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandtable</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boulevard art &amp; culture</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardio VR</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curiscope Virtual-tee</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dismounted Soldier Training System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Engine Explorer</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ER VR – virtual reality</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical Training Simulation</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EyeSim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>GestureTek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Google Earth</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Google Expeditions</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3.1. Direct Instruction

Direct instruction has theoretical roots in Behaviorism where learning is linked with stimulus-response conditioning, and rapid pace drill or structured lesson plans generates and supports student engagement through pacing and immediate reinforcement (Conole, Dyke, Oliver & Seale, 2004). In a direct instruction learning experience, the goal is to acquire a skill set or knowledge base through drill, practice, reward, and recognition for accomplishment (Engelmann, S., 2008), which can be assessed through behavioral changes (Conole, et al., 2004). The educational strategy is to use tutorials, paced and repetitive instruction, supported by structured lesson plans to achieve the learning goals.

The House of Languages was an example of direct instruction, where students could learn English, Spanish, and German language vocabulary through interaction, practice, and reinforcement during visits to a VR environment filled with objects and friendly small animal avatars. In response to a written vocabulary word hovering over an object in the environment, learners repeated the word; when the pronunciation was correct, the screen displayed visual reinforcement in the form of star sparkles surrounding the objects or auditory reinforcement in cheers. When learners could not pronounce vocabulary words in the appropriate accent, the avatar repeated the word correctly encouraging the learner to try again thereby reinforcing appropriate pronunciation. The goal of House of Languages was to develop mastery of vocabulary, which is a limited skill or knowledge set.

### 3.2. Experiential learning theory

Students are engaged purposefully in real-life or virtual experience with their focus...
directed to reflecting on experience as a source of knowledge, skills, and values (Dewey, 1938). Learners interact with the environment in a variety of modes including thinking, seeing, feeling, handling, and doing, with the goal of supporting learning (Dewey, 1938). Experiential learning allows the learner to experience different environments directly through exploring and visiting. The fundamental basis for experiential learning is the active role of the learner in constructing knowledge as a behavior change through interaction with the environment (Santos & Carvaho, 2013).

Experiential learners could be actively engaged in hands on activity, doing something, or recognizing something (Dewey, 1938; Kolb, 1984). Kolb (1984) posited four learning styles that were active during experiential learning including observing, thinking, doing, and actively conceptualizing and experimenting within the experience. Reflection is an aspect of experiential learning (Conole, et al., 2004). Experiential learning theory supports the use of virtual learning because of factors necessary in real world experiences, such as cost, time, space (Duncan, Miller, & Jiang, 2012).

Examples of experiential learning can be found at Alchemy VR, an organization dedicated to producing realistic and aesthetic VR simulations and learning experiences, where experiential learning applications are available in many academic arenas. A learner could experience the event as lived in real life. One such experiential learning application is centered on the Apollo 11 trip to the moon.

Archived audio and video supports and recreations of spacecraft and locations enhance the Apollo 11 experience. In the experiential moon flight documentary, a learner may relive the 1969 experience by taking control and flying the command module, land the lunar lander, explore the moon's surface, deploy experiments, and land on earth through re-entry. The application aligns with the experiential learning model because the user is engaged in a simulation of an actual experience to observe, conceptualize, and take control within the experience. The outcomes are standard so learners do not experiment within the experience, but carry memories of the experience when returning to non-virtual settings.

In a second example of experiential learning, Google Expeditions allow learners to participate in or lead immersive virtual trips all over the world. For example learners can visit historical landmarks, swim with sharks, or travel outer space as groups of explorers receive guidance through collections of 360° and 3D images – choosing from a growing list of over guided 200 expeditions. Learners can watch, feel, think, and sometimes do within a virtual Google expedition. By virtually visiting and interactively exploring environments learners can further achieve more in-depth understanding of content. A secondary pedagogical foundation is discovery learning, where in some Google expeditions, learners can guide exploration at will based on desire to discover more.

3.3 Discovery learning theory
Discovery learning occurs when students learn new concepts through personal discovery. Students with prerequisite knowledge who have gone through previous
structured experiences are more likely to be successful at discovery learning (Robyler, Edwards, & Havriluk, 1997). Discovery learning builds on existing knowledge to discover new things; the learner applies inquiry-based reasoning, performs problem solving, makes decisions, and applies strategy. In discovery learning, the learner is experimenting while testing potential outcomes.

The VR educational application, EyeSim is aligned with discovery learning. EyeSim allows learners to enter training sessions and where learners can discover complex aspects of ophthalmological anatomy, and practice diagnosis, and surgical procedures repeatedly in a safe training environment. Led by inquiry, learners engage in an interactive model that allows animated exploration of the structures and functions of the eye and supporting anatomy. Students can participate in deliberate practice, make decisions, use strategies, and learn through personal discovery as they explore and experience various ocular, nervous system, or other ophthalmology concerns and issues.

Boulevard art & culture is a second VR application that aligns with discovery learning. The learner can navigate through the collections with narration and zoom-in of visual art related to topic and period as housed in museums and galleries of international fame. Previously, students of art and art history would need to go in person to study these sources. Now, led by personal inquiry, students can navigate art from many cultures across many centuries in a VR world. Using existing art knowledge students can expand on their understanding and appreciation by discovering new artistic features.

3. 4. Situated Cognition
Situated cognition can occur within a community where individuals access the context specific, knowledge and practice embedded within the community (Lave & Wenger, 1992). In situated cognition, students become observers and actors within a virtual environment. Students could observe and follow others who are social models, who engage in role-playing, who practice skills within social or contextual situations, and who engage in social interaction and communications with others to learn (Bouta & Paraskeva, 2013). Valuable learning can occur in settings considered dangerous in real life such as a virtual environment for improved disaster risk reduction (Caroca, Bruno, & Alderbate, 2016). Situated cognition allows learners to develop multiple skills context based collaborative learning and involves the potential transfer of knowledge and skills to reinforce learner’s knowledge or learning in real world settings.

The Dismounted Soldier Training System is an example of situated cognition where teams of soldiers train for rapid response to various threat situations. The fully immersive virtual scenarios recreate environments that would be dangerous or treacherous in life. The life-like details that participants see and hear allow soldiers to conduct motion maneuvers. Communication exists between team members as they individually and cooperatively develop solutions to perilous scenarios. Military experts evaluate team responses based on real life experiences.
A second example of situated cognition is Anatomage Table where learners work with a virtual 3D application that shows the anatomy of a young, healthy, and virtual cadaver. Users can manipulate the view of the model through multiple layers of skin, muscle, organs, bone, and nervous system. A virtual scalpel allows learners to dissect the virtual cadaver. The Anatomage table supports individual or social interactions in various activities for potential learning while viewing and manipulating the virtual human cadaver. Teams of learners develop skills in concert and the Anatomage table can receive communications from participating students for specific requests allowing students to experiment within the VR application.

3. 5. Constructivism
In constructivist learning, learners construct or make sense of experience in ways that are personally meaningful (Papert, 1996). Constructivists gain knowledge and understanding through reflecting on or making sense of experiences, where learners engage and interact, and conduct activity (Papert, 1996). Constructivism relates closely to experiential and discovery learning (Fowler, 2015) but adds the construction of personal meaning by the learner as a final step. In a constructivist application, the learner has an opportunity to actively organize input from experiences (Ormrod, 2008). Learners, who mindfully construct new learning, can apply the insights in multiple contexts over and over in new environments, in contrast to learners, who have mastered learning in a less dynamic process such as by rote (Langer, 2000). A constructivist environment provides opportunity and supports students in applying their knowledge.

Tilt Brush allows users to construct artwork in a virtual environment. Artists or art students can rapidly construct illustration, fine art, or design using a multitude of color and effects in three dimensions. In this sense, Tilt Brush reaches the highest level of experiential learning where learners can act, experiment, and reflect within the experiences. In addition, Tilt Brush allows artists to construct personal meaning as artists. Painters and other artist imagination are stimulated by development of ideas and mental models that results in the creation of original works of art.

Virtual Battleship 3 is another example of constructivist learning; the flexible, high detail, application has some game like features, but ultimately allows learners to set up various scenarios, where tactical decisions determine outcomes and next steps. Learners are actively experimenting within a rapidly changing environment and constructing new understandings and skills in the process. Successful outcomes provide feedback for participants. Virtual Battleship has been selected as training device by the US army because the knowledge and skills generated within the virtual environment can be transferred to real life contexts. Virtual Battleship 3 was found to have some secondary pedagogy including situated cognition, where learning emerges in response to specific contexts, and discovery learning, where the learner is led by inquiry, in this case, inquiry into rapidly changing battle conditions.

3.6. Unclassified approaches
UN – does not fit into any of the other pedagogical foundations.
Table 2 displays results of other less significant pedagogical foundations that were identified for each VR educational application.

**Table 2**  
Other Pedagogical Foundations for VR Educational Applications ($n = 35$)

<table>
<thead>
<tr>
<th>Educational Application</th>
<th>Direct Instruction</th>
<th>Experiential Learning</th>
<th>Discovery Learning</th>
<th>Situated Cognition</th>
<th>Constructivism</th>
<th>Unclassified Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D White House Gallery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agent Cayley Virtual Reality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alchemy VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altspace VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomage Table</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomy VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomyou</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apollo 11 VR Experience</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Augmented REality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandtable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boulevard art &amp; culture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardio VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curiscope Virtual-tee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dismounted Soldier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Explorer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ER VR – Virtual Reality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EyeSim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GestureTek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Google Earth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Google Expeditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House of Languages VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InCell VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InMind VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>King Tut VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LKDF Interact – Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magi Chapel VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine and Offshore</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MoleculE VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROteinVR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilt Brush</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titans of Space</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toti Submarine VR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual Anatomy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual Battlespace 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR Earth in Solre System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
At least one other pedagogical foundation was determined to be associated with 22 of the VR educational applications; with eight applications having two, two applications having three, and 13 having no other identified pedagogical foundations.

4. Discussion and conclusions
In this study, the research team used a directed content analysis study to identify pedagogical foundations of VR educational applications that lacked articulation of specific pedagogies. The directed content analysis included aligning text and visual content to an existing theoretical model (Kebritchi & Hirumi, 2008), which proved useful as an aid to categorizing pedagogical foundations of specific learning applications as shown in Table 1. The present study meets a need to clearly identify pedagogical foundations of VR learning applications (Conole, 2004; Fowler, 2015; Kebritchi & Hirumi, 2008; Mikropoulos & Natsis, 2011) and allow educators to evaluate use and effectiveness (Stefan et al., 2016).

4.1. Limitations
Findings of the study are limited to the sample we used. Members of the research team reached consensus on categorizing pedagogical foundations of each application chosen for the analysis. However, one limit of the study is the qualitative and theoretical nature of the analysis where interpretation played a role in identifying the pedagogical foundations as defined in a theoretical model. In effect, no one right or absolute answer exists. Additionally, content analysis is descriptive, allowing researchers to identify descriptions from existing human communication. The process was ideal for our intent to use visual and text based content as indicators of pedagogical foundations, but also meant, we could describe what we found but not motivations.

4.2. Summary of Results
The Kebritchi and Hirumi theoretical model was useful as a point of reference in identifying inexplicit pedagogical foundations. Experiential learning emerged as the most common pedagogical foundation in 24 applications. The research team also found pedagogical features aligned with direct instruction in two applications, with discovery learning in four applications, with constructivism in three applications, and one with situated cognition for individuals and communities in one application. In a second round of analysis, the research team identified secondary pedagogical potentials in several applications. Discovery as an aspect of experiential learning was the most frequently identified second pedagogy (13 in 24 applications).

4.2.1. Experiential, Discovery, Constructivist, Situated cognition applications
The majority of the VR educational applications analyzed in this study were learner centered, where the learner explored, experienced, questioned, or constructed meaning within an enriched environment as compared to smaller numbers of direct instruction pedagogy. The distribution of pedagogical foundations was similar to findings by other researchers who also reported a preponderance of learner centered pedagogies.
Learner centered pedagogies are consistent with the work of germinal educational theorists (Dewey, 1938; Kolb, 1984; Lave & Wenger, 1991) and may represent a trend away from behaviorally oriented pedagogies such as direct instruction where the teacher plays a larger role.

4.2.2. Direct Instruction
Even applications that employed a direct instruction foundation took place in a VR environment offering visual and kinesthetic support for learning beyond flash cards or other drill prompts. For example, House of Languages VR featured visual images the learner could point to while moving around a room with congruent objects such as those found in a kitchen or playroom. House of Languages VR replaces a flash card drill with a directed lesson that included an environment designed to support the learner experience through discovery.

4.2.3 Secondary pedagogies
Some VR educational applications were found to have elements of secondary pedagogies in place. For example, InCell VR immerses the learner in a cellular environment where the learners outrun a virus wave invading a single cell. Learners can enter protein (later traded for speed) as they race the virus. InCell VR has elements of experiential as learners experience a specialized environment and discovery as they develop skills to navigate the environment. Other examples of secondary pedagogies are included in the results of analysis section (Table 2). Experiential and discovery learning were the most common combinations.

4.2.4. VR Designers
Some VR educational product developers consistently used specific pedagogies even when the commitment was unstated. For example, Alchemy VR has constructed multiple realistic experiential learning products and many have won recognition for beauty and originality. Unimersive has a similar orientation to experiential or discovery learning and sometimes used imaginary environments where learners could navigate cellular or neural pathways. Eon Reality, the designers of EyeSim, developed numerous discovery based learning applications across a range of disciplines including medical, engineering, and art. Learners actively move through environments where inquiry determines next steps in many Eon Reality applications. Bohemia Interactive developed the constructivist, context based Virtual Battlespace 3 that challenges learners to develop rapid solutions in response to shifting scenarios. Bohemia Interactive has a gallery of similar applications that emphasize the holistic approach to synthesis and problem solving within flexible scenarios.

4.3. Implications for educators and VR designers
Educators may find the theoretical model and analytical process tested in the current study very useful in preparing for the sweeping changes that VR could bring to education at every level. A variety of corporations, educational institutions and laboratories are developing VR applications that come into the marketplace on an almost daily basis. Clear statements of pedagogy are rarely found in these new
applications (Fowler, 2015, Mikropoulos & Natsis, 2011). However, national, regional, and local educational leaders and VR developers need a clear perspective on the pedagogy to prepare for and align the new VR applications with existing educational teaching and learning methods, (Stefan et al., 2016; Kahai et al., 2013; Lovequest et al., 2015; Psotka, 2013) and to assess and evaluate the new applications (Ludlow, 2015). The theoretical model (Kebritchi & Hirumi, 2008) and directed content analysis method used in this study could assist educators in preliminary assessing and evaluating VR educational applications by using readily available public data before committing to purchase and further implementation of a specific application.

Specific findings from the analysis could also be helpful for educators and VR designers. Descriptive examples of specific applications included in the results and discussion section could assist educators in recognizing similar pedagogies in other instances. Educators will find explicit pedagogical foundations useful as they incorporate the new technology into a comprehensive curriculum where multiple learning opportunities are available. The VR applications reviewed for this analysis did not included extended curriculum materials. VR designers could build on the engaging, educational opportunities available in VR by incorporating and communicating stronger pedagogical foundations. Furthermore, VR designers could expand use of the applications by developing guidelines for curricular use.

Conole et al., (2004) suggested that e-learning practitioners experienced the array of pedagogical theory as “overwhelming” (p. 18) and suggested building toolkits to support learning. VR designers or educators, who review the findings, could see the pedagogically related potential for an expanded version of each application that includes additional curriculum materials to stimulate reflection and build insights. A more conscious design that builds on clear pedagogical foundations might construct more effective VR learning experiences (Fowler, 2015) Finally clearly articulated pedagogical foundations could assist researchers to move beyond identifying basic pedagogical characteristics and study the nuances of effective practice.

4.4. Conclusions
Ultimately, the outcomes may depend on how educators choose to use VR educational applications. The innovative nature of VR depends on access to visual and kinesthetic experiences previously unavailable in traditional classrooms. We found the experiences aligned with experiential, discovery, situated cognition and constructivist pedagogies. In addition, VR provides supportive environments for direct instruction and situated cognition that may engage students and support skill development. Vision has been accepted as an aid to learning in the past. “The eye,” Humboldt wrote, “was the organ of ‘Weltanschauung’, the organ through which we view the world but also through which we interpret, understand and define it.” (Wulf, 2015, p. 248). As virtual reality educational applications become more pedagogically viable, they create a previously unimagined way to experience and view the world. Educators and VR designers have an opportunity to optimize learning through cogent application of pedagogical principles.
References


Appendix A

References for all VR Educational Applications contained in this study (n = 35)

http://fox3d.com/vr
InCell VR (2016). Retrieved December 6, 2016 from
InMind VR (2016). Retrieved December 6, 2016 from
King Tut VR (2015). Retrieved December 7, 2016 from
https://www.eonreality.com/portfolio-items/king-tut/?portfolioCats=333
LKDF Interact - Diesel Engine Operation (2015). Retrieved on December 7, 2016 from
Magi Chapel VR (2016). Retrieved on December 7, 2016 from
https://www.eonreality.com/portfolio-items/magi-chapel-vr/?portfolioCats=333
Marine and Offshore Technology (2016). Retrieved on December 7, 2016 from
https://www.eonreality.com/portfolio-items/virtual-technology-training/
Molcule VR (2016). Retrieved on December 7, 2016 from
PROteinVR (2016). Retrieved on December 7, 2016 from
Tilt Brush (2016). Retrieved December 5, 2016 from
http://store.steampowered.com/app/327140/
Titans of Space (2015). Retrieved December 6, 2016 from
Toti Submarine VR Experience (2016). Retrieved December 4, 2016 from
Virtual Anatomy Simulation (2016). Retrieved December 7, 2016 from
https://www.eonreality.com/portfolio-items/virtual-anatomy-simulation/
Virtual Battlespace 3 (2016). Retrieved December 5, 2016 from
https://bisimulations.com/virtual-battlespace-3
War of Words VR (2014). Retrieved on December 7, 2016 from
Appendix B

Content analysis focused keyword scheme for VR educational applications used in this research.

Direct Instruction pedagogical search terms
  drill
  feedback
  guided
  lessons
  paced
  practice
  skills
  tutorial

Experiential Learning pedagogical search terms
  encounter
  engage
  experience
  explore
  immerse
  involved
  journey
  recognize
  reflection
  tour
  view
  visit

Discovery Learning pedagogical search terms
  apply
  build
  decision-making
  develop
  discover
  inquiry
  problem-solving
  question
  strategy
  test

Situated Cognition pedagogical search terms
  coaching
  communicate
contextual
cooperaeive
interaction
models
mentoring
observation
role-play

Constructivism pedagogical search terms
constructs
creates
engages
environment
interacts
meaning
real-world

Unclassified Approaches pedagogical search terms
creative
experiment
hybrid
innovate
mixed
non-traditional
play
Appendix C

Content analysis coding scheme for VR educational applications used in this research

Organization type for VR educational application
  - Private Company = CO
  - Public Corporation = IC
  - University or Public Foundation = UV

Discipline of VR educational application
  - Academic Subjects = AS
  - Medical = ME
  - Military = MI
  - Engineering or Architecture = EA
  - Multi-purpose = MP

Pedagogical foundation for educational application
  - Direct Instruction = DI
  - Experiential Learning = EL
  - Discovery Learning = DL
  - Situated Cognition = SC
  - Constructivism = CN
  - Unclassified Approaches = UN
Acknowledgements

The research team acknowledges and appreciates the support of Dr. Mansureh Kebritchi, Research Chair of the Center for Educational and Instructional Technology (CEITR) at the School of Advanced Studies, University of Phoenix.
Educators need clear pedagogical criteria to prepare, apply, assess, and evaluate VR applications.

Directed analysis of public content showed evident but unstated pedagogies in VR applications.

Learner centered, experience based pedagogies were found most common in sample of 35 VR applications.

Elements of secondary pedagogies were found in some VR educational applications.

VR designers could expand use of the applications by developing guidelines for curricular use.