Visual Fidelity in Educational Simulations

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ABSTRACT

There is an assumption among designers in the educational technology community that simulations with high visual fidelity facilitate learning better than those with low visual fidelity. This assumption traces its roots back to similar beliefs established during the mid-1990’s, when aviation and mechanical simulators began to be used extensively for training. It is based on the notion that high visual fidelity should logically generate high levels of presence. According to cognitive theories of situated learning and constructivism, high levels of presence should support enhanced learning, by situating learners in meaningful contexts, facilitating discovery-based learning and collaboration, and enabling learners to experience alternate perspectives.

However, there is little evidence to support this conviction. Indeed, some researchers believe that high visual fidelity may impede learning for novices. Recently, a new theory has emerged, which suggests that the use of explicitly engaging content may be more effective at generating presence and supporting learning than high visual fidelity. Since producing high fidelity simulations demands considerable computing and financial resources, this theory has significant implications for the producers of educational simulations.

This paper explores current theories of fidelity, learning and presence, and reviews research in the field. It concludes with a proposed experiment for an initial investigation of the relationships between these concepts. The hypothesis to be tested is that designers of educational media can lower the level of visual fidelity in a simulation without decreasing the learner’s levels of presence or negatively affecting learning, through the use of explicitly engaging content.
1 Introduction

As computing power improves and visual display technologies become increasingly sophisticated, the use of 3D and stereo computer animations for learning has become commonplace. There is an underlying assumption by designers of these educational simulations that this high graphic fidelity must result in better learning, since it should intuitively increase the learner’s sense of presence and engagement. According to cognitive theories of situated learning and constructivism, these sensations should, in turn, support visual perception of the simulation content and therefore knowledge construction (Mott, Callaway, Zettlemoyer, Lee, & Lester, 1999; Roussou, 2004).

However, there is little evidence to support this design assumption. In addition, many researchers contend that high fidelity and sophisticated technology cannot create presence on their own; they must be supported by engaging content. As a result of their work at Disney, Pausch, Snoddy, Taylor, Watson and Haseltine (1996) suggest that the level of fidelity in a virtual environment (VE) could be reduced without negatively affecting participant levels of presence though the use of engaging content.

Since there is a suspected link between levels of presence and learning, this finding could have significant implications for the production of educational simulations. If it is possible to achieve the same levels of presence and learning by using a 2D simulation as one produced in 3D simply by creating more engaging content, educators may be able to shift some of their resources away from the production of complex computer-generated images (CGI) to support other facets of their learning programs.

This paper addresses these issues through a review of the relevant literature. Based on this review, I propose an experiment to extend the work of Pausch et al. into the domain of educational media production. The research design will test the hypothesis that creators of educational simulations can lower the level of visual fidelity without decreasing a learner’s levels of immersion and presence by using explicitly engaging content.
2 Simulations in Education

In computer graphics, the term “simulation” generally refers to an electronically-generated representation of a real or abstract system, process or environment. Interactive capabilities and image motion are often assumed to be integral parts of such a system (Williams, 2003). For the purposes of this paper, an educational simulation differs from a data visualization in that the former is designed to meet a series of learning objectives. It has specific content that the learner is meant to explore and use to build knowledge. By contrast, data visualizations present empirical data in a manner that facilitates the interpretation of that data in a specific context.

Learning as a concept is complex and difficult to characterize. Specific descriptions often refer to specific types of learning tasks. Learning may occur in a broad variety of ways, some of which may require the construction of spatial knowledge, the acquisition of new motor skills, or a change in conceptual understanding of a specific topic, to cite just a few examples. Goodyear, Njoo and Hijne offer a succinct definition of learning that will suffice for this paper: “cognitive transactions of the learner that are meant to transform information into knowledge” (1991, as cited in Williams, 2003, p. 4).

As different learning tasks require different pedagogical approaches, the nature of each task should be considered by designers when planning their simulations (Caird, 1996). Although taxonomies of educational simulations vary, Alessi (1988) offers a succinct summary. He describes procedural and situational simulations as those in which we want the student to learn how to do something; whereas in physical and process simulations, we attempt to help students build knowledge about phenomena and concepts.
The guiding principles of educational simulation design are based on a combination of intuition from experiences in related instructional design and findings from research in the field of aviation training. In general, educators believe that transfer of learning increases as the similarity between the learning situation and the situation being modeled increases (Alessi, 1988). The logical corollary to this is that learning in the real world upon which the simulation is based would offer the best transfer (Caird, 1996). However, as Caird points out, this is not necessarily so.

Factors such as cognitive load, levels of expertise, individual learning styles and prior learning can all affect a learner’s cognitive processes. This suggests that the learning process in simulations is more complex than originally thought and that real world learning may not be the best option. As a result, some researchers have proposed varying levels of fidelity in a simulation to match a learner’s level of knowledge. This concept is explored further below.

3 Fidelity

In a broad sense, fidelity describes the degree to which a simulation is similar to the objects or situation it represents (W. Choi, 1997). In this definition, reality is the highest level of fidelity.

3.1 Types of fidelity

Researchers in this domain refer to different categories and types of fidelity, depending on the nature of their investigations. The definitions offered by Hays and Singer (1989) are often cited. They refer to physical fidelity as a reflection of how authentic the interface is, with respect to manipulation and feedback by the user. This is frequently a feature of training systems for manual or motor skills. Functional or operational fidelity describes how well the simulation represents the workings of the system being modeled. It is usually associated with conceptual or cognitive process tasks. Caird (1996) also refers to psychological fidelity: the degree to which a simulation reproduces the sensory and cognitive processes that a student might experience in the real world.
Instructional designers often assume that high resolution displays and high levels of interactivity will automatically generate psychological fidelity and transfer of learning. This belief can be traced back to the early days of simulation design for aviation training. Research findings from this era still dominate discussions of fidelity and learning, despite the fact that technology has advanced considerably since then; computer simulations are now used for learning in domains from business to biology to baking.

While the levels of fidelity available in computer simulations are relatively low compared to those in many mechanical simulators, valuable findings may still be extrapolated from the considerable research done in this field.

3.2 Fidelity in aviation training

The range of fidelity in mechanical flight simulators varies greatly from that of today’s virtual computer-generated environments. In aviation research studies using radar control panels to investigate fidelity, the low-fidelity versions were full-size mock-ups of the control panel that used the real controls; the high-fidelity versions were the real plane. As such, watching a VE simulation on a desktop computer and interacting with the device through a computer mouse may seem quite feeble by comparison (Alessi, 1988).

For years, instructional designers working in aviation education believed intuitively that using high fidelity simulators – that is, mock-ups that used real plane controls, motion platforms and changing views out the window would result in the most effective learning by the students (Alessi, 1988; Noble, 2002). Despite many years of research into this field, there is no clear evidence to support this assumption. Results from a variety of studies are mixed, suggesting a more complicated, often counter-intuitive relationship between fidelity and learning (Alessi, 1988).
One significant line of thinking that did emerge from this research was that there may be a relationship between fidelity, cognitive load and expertise. Learning transfer for novices was shown repeatedly to be better in low fidelity simulators, while experts often did better in high fidelity environments. Researchers suggest that this may be due to a cognitive overload on the part of the novices; a high fidelity environment is more visually complex than a low fidelity model (Miller, 1974, as cited in Alessi, 1988). Processing all of the incoming stimuli in a high fidelity condition, in addition to thinking about performing the task at hand, may overwhelm novices.

3.3 Visual fidelity

Visual fidelity is implicit in all the definitions of fidelity outlined above; yet it is rarely defined or examined explicitly in the context of learning simulations. Since the field has not been studied in depth, (many of the technologies are just a few years old), the assumption from the aviation and mechanical training community that high fidelity supports learning better than low fidelity has been perpetuated among designers in the computer-based domain (I. Choi, 1998).

Visual fidelity can refer to a number of different attributes of graphic design, such as image resolution, dimensionality, shading and structure from motion. Research in the field of visualization strategies and applications is relatively new; as such, little empirical data is available to inform the design of educational simulations.

To complicate the issue further, most research in the realm of 3D, stereoscopic and virtual environments fails to consider visual design elements as separate entities from interactive capabilities (such as kinetic depth navigation). It is also common to find a lack of control in these studies for other sensory inputs that may affect learning in such environments. These can include aural, haptic and motion stimuli. Nor does the research account for the ability of the simulation content to actively engage learners.

For the purposes of this paper, I have classified visual fidelity into two categories: realism and complexity.
3.3.1 Realism

Surprisingly, a concrete definition of realism that pertains to our visual processing system is not easy to pin down. Our perception of the information captured and processed by our visual system is not always reflective of the physical entity being viewed (Ware, 2000). We have other cognitive, affective and sensory influences on our visual processing system.

Photo-realism describes a design approach that generates images to represent reality as it is perceived by the learner, rather than images that reflect physical reality (Ferwerda, 2001). This is important to understand, as it is our perception of reality that affects learning, not reality itself. An interesting criterion presented for photo-realism is that “the image has to produce the same visual response as the scene even if the physical energy coming off the image is different from the scene” (Ferwerda, 2001).

Daniel (1992, as cited in Wherrett & Tan, 2005) suggests that the goal of photo-realism may be achieved when improvements in image quality (such as higher resolution) do not affect or improve the viewer’s perceived realism.

The value of perceived realism over reality itself was demonstrated by Dittrich (1977, as cited in Alessi, 1988), who found that perceived realism was more important to learning than actual realism in business games.

More recently, in their studies of telepresence and learning, Fowler and Mayes (1997) demonstrated that fidelity of physical interactivity with objects in a skill-based learning simulation – that is, how objects behave when controlled – has more impact on learning transfer than photo-realism.

Resolution in computer graphics relates to the concept of photo-realism, in that it describes the level of image detail. Resolution is typically measured in pixels or number of lines scanned on a screen. Higher levels of resolution are generally associated with enhanced photo-realism (Ferwerda, 2001).
3.3.2 Complexity

Complexity relates to the amount of information in the image that the learner has to process. It is a critical concept in educational design, as too much complexity can tax the learner and create cognitive overload (Reigeluth & Schwartz, 1989, as cited in W. Choi, 1997). Yet too little can dull the learner’s engagement with the content.

One facet of complexity is the number of objects in a simulation that the learner must recognize, understand and perhaps interact with. Varying the number of objects is one way that the developers of aviation trainers have historically controlled fidelity and cognitive load; as a learner advances in expertise, the number of objects that appear in her simulation increases (Alessi, 1988).

Dimensionality is an aspect of complexity in CGI that has emerged as a design consideration only recently, since access to 3D, stereo and immersive technologies for virtual environments has become commonplace.

Two-dimensional computer-based animation has been available for several decades now. It varies in both realism and complexity, depending on the goal of the learning task and (often more importantly), the project budget.

Designers of 2D simulations can draw on any number of monocular cues to add depth, texture and motion to their visualizations. These include linear perspective, texture gradient, occlusion, depth of focus, cast shadows and shape from shading.

Two-dimensional space can be considered as part of the 3D design space. One may flatten a 3D simulation and present it in a 2D space, but the reverse is not possible (Ware, 2000). Both 2D and 3D simulations can be viewed on a 2D screen or monitor.
One of the primary differences between simulations produced in these two dimensions is the way in which they are built and displayed. Two-D scenes or images are generally constructed from pre-drawn flat images; whereas 3D images are created from objects that have been rendered from all angles (360°). A 3D object can be displayed from any angle by applying an algorithm to it. However, a 2D object can only be seen from the existing pre-drawn angles (Howland, 1998).

Distinguishing the difference in how they are perceived is more complex. Three-dimensional simulations can access all of the monocular cues described above. In addition, 3D CGI generally includes motion perspective and motion parallax information. These motion cues have been shown to be one of the most powerful cues for signifying depth (Ijsselsteijn, de Ridder, Freeman, Avons, & Bouwhuis, 2001; Ware, 2000).

Recent work in 2D attempts to exploit motion parallax by creating different layers of scenes and objects and moving them independently. This effect is often called 2D3D or two- and-a-half D.

One way in which 3D simulations vary greatly from those in 2D that is rarely mentioned in any comparative research is kinetic depth: the rotational interactive and navigational capabilities available in 3D. Most interactive 3D simulations offer the learner the ability to manipulate a central object or the scene so that she can see it from all angles, or walk or fly though it. Such capabilities are significant for supporting learning; yet researchers studying the effectiveness of 3D frequently neglect to separate the effects of such interactivity from those of visual fidelity in their experiment design.

Stereo simulations are less common than 3D but are growing in popularity as the cost of technology and content development continues to drop. Stereo makes use of all of the visual cues mentioned above, as well as stereopsis. In specific situations, this binocular feature of simulations can enhance depth perception of 3D objects and spaces (Ware, 2000).
Stereo is often a feature of immersive or virtual environments, although it is possible to have one without the other. Stereo VE’s tend to use one of two approaches. In the case of a single learner, she may wear a head-mounted device (HMD) that blocks out her view of the world and focuses her visual attention completely on the stereo image fed to the HMD. When multiple learners are involved, a more common and often more manageable format is the use of large projection screens. The layout of the screens can vary from a single front display to a 6-sided CAVE.

4 Fidelity, Immersion and Presence

Creating a high level of immersion is often a key goal in the design of educational simulations, since immersion correlates to a sense of presence (Mania & Chalmers, 2001; Mantovani & Castelnuovo, 2003; Salzman, Dede, Loftin, & Chen, 1999) and researchers suspect that presence may play a central role in supporting learning in computer-generated environments (Dalgarno, Hedberg, & Harper, 2002; Fowler & Mayes, 1997; Winn, Windschitl, Fruland, & Lee, 2002; Zayas, 2001). However, discussions of presence are limited in the literature to studies in 3D virtual environments.

I suggest that presence is also relevant to learning in lower fidelity simulations. One may experience a deep sense of presence in a range of pursuits, from reading a book to chasing dragons in a VE (Ware, 2000).

The concepts of both presence and immersion are relatively new within the field of educational simulations; as such, the relationships between them and fidelity are not well understood. The section below offers a broad definition of both presence and immersion and discusses common perceptions of how they relate to fidelity.

4.1 Immersion

Immersion is generally considered to be a factor of technological design. It refers to the effect created when inputs to a learner’s visual, aural and other senses are controlled by the technology of the simulation, effectively blocking out unrelated input from the outside world (Mantovani & Castelnuovo, 2003).
Visual display factors that contribute to a sense of immersion are generated by technology that is inclusive, extensive, surrounding and vivid (Slater and Wilbur, 1995, as cited in Mania & Chalmers, 2001). More specifically, these factors may include:

- the distance between the user and the display (Swaminathan & Sato, 1997);
- the field of view (FOV) of the display (Ijsselsteijn et al., 2001);
- visual cues such as motion perspective, structure from motion and occlusion (Ijsselsteijn et al., 2001; Lombard & Ditton, 1997, as cited in Sas & O'Hare);
- an egocentric perspective (Wickens, C. D., Liang, C., Prevett, T., Olmos, O., 1994, as cited in Ostnes, Abbott, & Lavender, 2004).

When one is immersed, she may then experience a sense of presence.

### 4.2 Presence

Presence is often described as an outcome of immersion. It relates to our ability to perceive and interpret inputs to our senses; as such, it has significant potential as an influence on the learning process.

In their work exploring the cognitive factors underlying presence, Sas and O’Hare describe presence as “a psychological phenomenon, through which one’s cognitive processes are oriented toward another world, either technologically–mediated or imaginary, to such an extent that he or she experiences mentally the state of being (there), similar to one in the physical reality, together with an imperceptible sliding of focus of consciousness to the proximal stimulus located in that other world (Sas & O'Hare, , p. 3).

Slater refers to the three crucial aspects of presence as: "the sense of being there in the environment depicted by the VE; the extent to which the VE becomes the dominant one, i.e. that participants will tend to respond to events in the VE rather than in the real world; the extent to which participants, after the VE experience, remember it as having visited a place rather than just having seen images generated by a computer" (1999, as cited in Mantovani, 2003, p. 209).
As is apparent from these descriptions, presence is somewhat nebulous and difficult to measure. Little empirical research has been done to link presence and learning. However, many designers believe that presence plays a similar role to engagement in learning, which makes it desirable in educational simulations (Schank, 1997, as cited in Fowler & Mayes, 1997; Mantovani & Castelnuovo, 2003; Winn & Jackson, 1999).

The concept of having to engage learners in order for them to experience effective learning is fundamental to teaching and instructional design principles (Gagne & Briggs, 1979; Schiefele, 1991). “What information we select to attend to, and how intently, is still the most important question in learning” (Csikszentmihalyi & Hermanson, 1995, p. 68).

However, many suspect that presence cannot be generated by technology alone; that there are other cognitive and affective factors that can improve or degrade the learner’s sense of presence (Fowler & Mayes, 1997; Pausch et al., 1996; Williams, 2003). In fact, some researchers suspect that cognitive engagement with the content of a simulation is more effective at generating a sense of presence than high levels of visual fidelity (Mantovani & Castelnuovo, 2003).

The notion of a relationship between visual fidelity, engaging content and learning raises interesting questions with respect to the allocation of resources in simulation design. Could a low level of visual fidelity of an educational simulation generate the same levels of learning as a higher level of fidelity through the use of explicitly engaging content? If so, what aspect of fidelity would be the most appropriate to lower – dimensionality, realism, resolution, or the number of objects? How does presence fit into this theory; are high levels of presence necessary to facilitate learning? Does presence generated by high levels of visual fidelity have the same effect on learning as presence generated by engaging content coupled with low fidelity?

The next section explores some of the more relevant research on the relationships between visual fidelity, presence and learning, in an effort to begin to address some of these questions.
5 Related Work

Research into the effects of visual fidelity on learning in computer-generated simulations is still young; the works discussed below only begin to explore the complex nature of the relationship between these two domains.

In considering this research, it is important to remember that our perception of the visual stimuli presented in a CGI is not determined solely by our visual processing system; other factors such as cognitive load, working memory, learning objectives, individual characteristics and interaction design also play critical roles in shaping the learning process and its outcomes (Salzman et al., 1999). It is almost impossible to determine that a specific treatment of a visual display parameter such as dimensionality or motion parallax could be responsible for a specific effect on learning. We can only use the findings below as guidelines for future research.

5.1 Realism & complexity

Discussions in the literature of graphic or photo-realism as described in Section 3.3.1 suggest that its effectiveness in supporting learning relates to the type of learning task being presented. For situations that require the memory of objects, visual discrimination, spatial abilities, etc., a high level of graphic realism seems to be a key factor in making a virtual training efficient (Mantovani & Castelnuovo, 2003). Such learning tasks might include flight, drive or surgical simulators. However, this theory has not been explicitly tested.

By contrast, tasks that as less visual in nature, requiring cognitive abilities such as problem solving, role play and conceptual change seem to require a stronger sense of psychological presence. Learning support in these simulations depends more on the context, content and interaction design than on photo-realism (Mantovani & Castelnuovo, 2003).
Several researchers note that too high a level of detail or realism in an image can actually have a negative impact on learning, as there may be too much information for learners to process and salient details may be lost in the noise (W. Choi, 1997; Kwinn, 1997).

This issue of visual complexity relates to theories raised earlier concerning cognitive load. How much information can our mental and visual systems process at once? When do they become overloaded and fatigued? What visual and verbal information demand more “processing power” than others?

One approach to managing cognitive load suggested in the literature is to vary the level of fidelity of a simulation with the level of expertise of the learner (Alessi, 1988; Caird, 1996; Grunwald, 1968; Noble, 2002; Weiss, Knowlton, & Morrison, 2002; Winn & Jackson, 1999). This idea was originally proposed by Miller (1953, as cited in Noble, 2002) in reference to the physical aviation trainers of that era. While the notion holds promise for translation into the CGI training domain, few researchers have attempted any empirical studies to test the theory’s applicability.

5.2 Dimensional fidelity

The notion that higher fidelity results in enhanced learning continues to pervade the educational technology community, particularly with respect to the use of 3D, stereo and virtual environments. Designers who support this belief theorize that these sophisticated environments generate higher levels of presence than their lower fidelity equivalents. As stated earlier, the problem with this assumption is that there is little evidence to support it.
A few studies have been done that demonstrate that 3D simulations are better than 2D for spatially-related visualization tasks, such as path tracing and navigation (Ware, 2000). However, one cannot assume that the superior results obtained with 3D are due to high visual fidelity; they may be due instead to the enhanced interactivity inherent in the 3D visualization condition. Most 3D environments include interactive capabilities that enable the learner to rotate her viewpoint of the environment and objects in it, as well as navigate through the virtual space, a feature described as kinetic depth. Such interactivity is notably absent in 2D treatments in these studies. Yet, few of the studies that compare learning between 2D and 3D conditions treats this enhanced interactivity as an independent variable.

One experiment that did control for the interactive factor when comparing 3D stereo to non-stereo found that the use of kinetic depth was more effective for path tracing tasks than was stereo (Sollennberger & Milgram, 1993 as cited in Ware, 2000). However, such a comparison does not exist between 2D and 3D.

Ijsselsteijn et al. (2001) published a related work, in which they found that motion parallax was more effective at generating high levels of presence than was stereo.

One oft-cited 2D-3D study that asserts the advantages of 3D compares a fully-animated 3D HMD immersive simulation that was complemented with haptic and aural stimuli, to a 2D line drawing program viewed on a desktop computer (Salzman et al., 1999). When considering visual fidelity parameters, this does not present a valid comparison; any discussion of 3D superiority here must be seen as inconclusive. Another visualization study explored viewing conditions for complex 3D data sets. The authors found some advantages for 3D, in that the subjects were better able to answer questions related to simultaneously viewing multi-dimensional objects and visually imagining the surface portrayed. However, no advantage was found for focused questions on content. More importantly, information gained from the 3D advantage was not retained over the long term (Wickens, C. D., Merwin, D. H., Lin, E. L., 1994, as cited in Ostnes et al., 2004).
Mania and Chalmers (2001) also studied varying levels of fidelity, comparing identical learning content presented in a 3D desktop display, 3D HMD, audio/slide combination and real world environment. They were exploring the effects of immersion on presence and memory. Their method was to videotape a classroom seminar, then use that as the source material for the creation of four educational simulations, delivered in the configurations described above. It is worth noting that the learning tasks in the seminar did not have spatial or visual components to them; nor did they require students to navigate through the virtual space. However, a series of questions on the learning experience did attempt to measure learners’ memory of certain visual information, such as the layout of the room.

The results of the study showed that learner recall of information presented in the seminar and the spatial layout of the room was significantly better for the real world condition, as compared to the HMD and audio delivery. Interestingly, there was no significant difference between the real world and the desktop display. Levels of presence were also significantly higher in the real world condition than any of the other conditions. There was no significant difference in presence between the desktop, audio, or HMD conditions. Surprisingly, levels of presence in the audio/slide condition were higher (although not significantly so) than the HMD and desktop conditions. The authors speculate that this may be due to the presence of live audio sounds from the original taped seminar, combined with our visual imaging capability. The authors conclude that the different levels of immersion tested did not affect levels of presence because the tasks were not dependent on the environment or interaction (Mania & Chalmers, 2001). This suggests that perhaps visual fidelity does not significantly affect presence.
In their comparison of immersive and desktop simulation environments, Winn et al. (2002) had somewhat different results. They compared ratings of presence and learning scores between students who worked in an immersive VE against those of students working with the same VE on desktop computers. Unfortunately, they did not describe the VE with respect to visual fidelity, dimensionality or stereopsis. A casual reference at the end of the paper suggests that it may have been a 3D environment. They found that students in the immersive environment rated their levels of presence and engagement significantly higher than did those using the desktop displays. Those using the immersive environment performed better on tasks requiring spatial learning, but there was no difference in learning between environments for tasks dealing with conceptual change. The authors concluded that immersive environments only offered an advantage for tasks that were spatially-related (Winn et al., 2002).

It appears that to date, there is no clear evidence that the use of 3D CGI offers a learning advantage over identical 2D content when the learning task does not require the use of kinetic depth and navigation control.

5.3 Presence

The work of Winn et al. (2002) referenced above offers one of the most comprehensive studies of presence as it relates to learning. Although the authors were able to correlate high levels of immersion with high levels of presence, there was no conclusive evidence that increased presence resulted in better learning.

Students who felt more present also rated engagement and enjoyment of the experience higher. This demonstrates a link between engagement and presence, but not between engagement, presence and learning. This runs counter to cognitive theories suggesting that enhanced presence can support learning by situating the learner in a meaningful context and encouraging collaboration (Duncan, 1995; Hung, Tan, Cheung, & Hu, 2004; Milne, 2003; Winn & Jackson, 1999).
In each study that involves immersion and presence, it seems that interaction design has a role to play. One reason for this may be that making conscious decisions to interact with an object in an environment interrupts the learner’s sense of presence, because she must shift her attention away from the virtual scene to the interface controls (Steiner & Tomkins, 2004). Sastry and Boyd (1998, as cited in Mantovani, 2003) believe that interactivity has more influence on a person’s sense of presence than the richness and faithfulness of the images.

The technical problems inherent in high fidelity VEs and immersive environments may also weaken a learner’s sense of presence by distracting her from the task. Such interruptions can be caused by a limited field of view, poor resolution of the head-mounted display or projection system, time lag and spatial error of the images, distortions introduced by the optics and/or algorithms, frame-rate limitations and perceptual-motor adaptation (Caird, 1996).

As Mantovani finds in his examination of the literature on learning and presence, the latter does not depend solely on visual stimuli; it is generated through a complex web of factors (Mantovani & Castelnuovo, 2003).

### 5.4 Content and presence

The factors affecting presence can be divided into those related to technology and those connected to human characteristics, such as the learner’s cognitive and personality aspects. The challenge for designers of educational simulations is to understand how these two domains relate.
Visual environments are desirable for learning because we can gather a lot of information from a picture quickly; however, the novelty effect of the types of imagery used in virtual environments does not last (Kwinn, 1997). One area of research that is recognized as significant by many authors but that has not been explored is the use of explicitly engaging content, such as that of a goal-based scenario, to support the generation of presence (Mantovani & Castelnuovo, 2003; Winn et al., 2002). As Caird points out, many virtual environments tend to rely on the novelty of the technology to engage the users and are effectively goal-barren (Caird, 1996).

This idea is supported by the findings of Pausch et al. (1996) in their studies of presence in the context of a VR ride. They were able to conclude that VR novices are unimpressed with the technology for its own sake; they care about what there is to do in the virtual world. When guests were given a concrete goal to achieve in the VE, they experienced higher levels of presence. This led the authors to wonder if the use of such explicitly engaging material could enable them to lower the fidelity of the VR without weakening the guests’ sense of presence. As an interesting note, they discussed the ability of high levels of presence in the desktop games of DOOM and the SIMNET tank simulator to compensate for any disruptions in presence caused by the interface; it appears that the player becomes so engaged in the task at hand that the interface becomes invisible.

Hoffman et al. (2000, as cited in Winn et al., 2002) explicitly tested the idea of using engagement to generate presence. They created a highly-engaging game-like VE for children who had been severely burned to use while they were having their wounds cleaned. These children experienced a significantly higher sense of presence than those who used a Nintendo game for the same purpose; they also felt less pain during the procedure.
Work by Chalmers et al. (2003) supports the notion that when a learner is deeply engaged in a task, low visual fidelity does not disrupt her level of engagement. Their work on attentional blindness studied subjects’ ability to perceive differences between parts of a simulation scene rendered in high resolution that formed natural foci of attention and the rest of the scene, which was rendered in low resolution. The subjects were so engaged in their tasks that they failed to notice the difference between the high and low resolution images.

It appears that many researchers in the field of educational simulation believe that technology alone cannot create presence: that the use of engaging content has a role to play (Fowler & Mayes, 1997; Pausch et al., 1996; Williams, 2003). Yet, as Heath reminds us, technology is not interactive; people are (as cited in Hawkey, 2004).

One theory of learner engagement that educational designers may apply effectively to address this need is that of disequilibration or cognitive conflict, as defined by Piaget (Moessinger, 1978). He defines “equilibration” is a driver for learning. This notion describes an intrinsic human need to find balance between our cognitive structures and our environment. It involves both assimilation and accommodation of new information and experiences and must be present for cognitive development to occur (Moessinger, 1978).

The concept of cognitive conflict can be closely related to dramatic conflict in storytelling. According to Hollywood screenwriting guru Robert McKee, conflict is at the heart of every good story; “Nothing moves forward in a story without conflict . . . . The Law of Conflict is more than an aesthetic principle; it is the soul of story. Story is metaphor for life, and to be alive is to be in seemingly perpetual conflict” (McKee, 1997, pp. 210-211). In his guidelines for storytelling, McKee asserts that as long as there is unresolved conflict in a story, the audience will remain engaged. The moment the conflict ends, so too will our attention.

This suggests that cognitive conflict or story as defined above may be useful as a means of creating engaging content that would enable designers to lower fidelity in an educational simulation.
6 Proposed Experiment

As mentioned previously, research into the relationship between visual fidelity and learning is still quite young; it is not yet possible to draw any conclusions that support one approach over another. There are suspected links between visual fidelity and presence, between presence and learning and between engagement and presence. The potential connection between the level of visual fidelity and engagement value of the content holds particular promise for designers of educational simulations. If they can achieve the same learning outcomes with low fidelity as with high fidelity, simply by using content that is explicitly engaging, they may be able to dedicate more resources to other areas of the learning plan.

In addition, it appears to be essential to identify the type of learning task to be addressed in the simulation. Non-spatially related tasks that do not require navigational or rotational viewing abilities may not require expensive 3D treatments.

Finally, no clear advantage for the high visual fidelity of 3D simulations over 2D has been demonstrated; all superior results for 3D learning environments are linked to the enhanced interactive capabilities of 3D that enable the learner to explore the kinetic depth of the VE.

As a starting point to explore these questions, I propose the following experiment.

6.1 Experiment design

Hypothesis: A 2D learning simulation that uses explicitly engaging content can achieve learning outcomes that are equal to or better than those achieved by an identical 3D simulation that does not use explicitly engaging content.

To test this hypothesis, I plan to compare two learning simulations that are identical in every way except their dimensional representation of the images. One would be 2D and one would be 3D. The learning task to be achieved would involve conceptual change on the part of the learners; it would not be a spatially-related task.
Specifically, the learning task would be to help rural Indonesian mining families learn how the inorganic mercury they use in their artisanal gold mining operations poses a severe risk to their health. This occurs in two ways: the first is when they burn the mercury off and inhale the vapours; the second is when they flush it into local waterways where bacteria convert it into organic mercury in the aquatic food chain and it contaminates the fish they consume daily.

Both simulations would have identical interface designs and navigational abilities. These would be limited to pan, tilt, zoom and changing scenes. Such a limitation is essential to control for 3D’s superior interactivity capabilities.

The experiment would run under four different conditions.

Condition One: A 2D non-engaging simulation. This simulation would use a straight narrative delivery of the facts that would follow a step-by-step explanation of how mercury reacts during the miners’ work and in the aquatic environment.

Condition Two: A 2D engaging simulation. This approach would deliver the same information using a storytelling methodology. In this condition, the simulation would tell the story of an artisanal mining family facing a life and death conflict. They wash inorganic mercury into the local river as part of their gold amalgamation process, but they don’t know that this is converted into organic mercury that contaminates the fish they consume daily as their primary protein source.

Condition Three: A 3D non-engaging simulation. This delivery would be identical to that of Condition One, except that the scenes and objects in the simulation would be created and rendered as 3D objects.

Condition Four: A 3D engaging simulation. This final condition would be identical to that of Condition Two, except that the scenes and objects would be created and rendered as 3D objects.
For each condition, I would measure the knowledge acquired and conceptual change achieved, with respect to how the learners can protect their health. I would also measure learners’ levels of presence for each condition, using the presence questionnaire developed by Witmer and Singer (1998, as cited in Mania & Chalmers, 2001) and adapted by Mania et al. There would also be a pre-test to determine the learners’ existing level of understanding of the issues.

I predict that the experiment would indicated a relationship between a learner’s level of presence and the learning achieved. I would also expect to find similar levels of both presence and learning between Conditions Two and Three.

7 Future Research

Clearly, our level of understanding of the relationship between visual fidelity and learning is embryonic. There are complex physical, cognitive and social factors affecting learning that domains such as HCI, cognitive science, educational technology and many others are just beginning to address.

As Ware (2000) suggests, the choices to be made by designers of educational simulations will not be as simple as whether to use 2D or 3D, but will involve selecting specific visual display cues to achieve specific learning outcomes. We need to develop a better understanding of how such cues support learning to develop design guidelines to support these choices.

Based on the results of my proposed experiment, future research questions could address the role of interactivity in supporting learning for specific tasks, as well as the need for a better understanding of the links between presence and learning in all environments, not just 3D.
The technological prowess of CGI and simulation offers enormous potential for learning. The challenge for designers in this field will be to remember that the needs of the learner must be their primary consideration. Appropriate technologies must be chosen to support learning; using technology for its own sake does a disservice to both current and future learners.
8 References


