The best way to predict the future is to create it: Introducing the Holodeck@UH mixed-reality teaching and learning environment

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Abstract

A challenge of online learning is enhancing students' sense of social presence, that is, their perception of “being there” with others. At the University of Hawai‘i at Mānoa College of Education, we are working on a research and development project with the goal of enhancing students' social presence through the use of a mixed-reality 3D virtual learning environment. Our project, the Holodeck@UH, attempts to bring the virtual world and the real world together as a mixed-reality “mash-up”. Using the Holodeck, on-campus and online students are able to come together both physically and virtually and take part in class and other collaborative activities. This article describes the initial phases of our design-based research effort in which we designed and built the Holodeck, from concept to advanced working prototype, and our initial evaluation efforts. Findings from an initial formative evaluation and usability study are presented and discussed.

Introduction

The topic of online learning conjures images of course management systems like Blackboard and Sakai, in which course materials are made available to students, students can submit their assignments to instructors and the class can discuss topics using discussion forums, text chat and in some cases audio and video conferencing. Given remarkable enrollments in online courses (Picciano & Seaman, 2008) and predictions that over 10% of all K-12 classes will be offered online by 2013 (Christensen, Horn, & Johnson, 2008), it is clear that educators and educational institutions see enormous value in online learning. However, course management systems are but one medium to enable learning via the Internet. Other mediums such as multi-user virtual environments (MUVEs), virtual worlds and serious games are gaining traction as viable learning technologies in educational institutions (Dalgarno & Lee, 2010; Livingstone, Kemp, & Edgar, 2008; McLellan, 2004). Arguably, the affordances of these technologies can provide for more social learning than traditional CMS, which can be socially isolating (McInerney & Roberts, 2004). Researchers are exploring a variety of MUVEs in order to learn how to best leverage the characteristics and capabilities of the medium to impact learning outcomes. For example, applications built using MUVE technology such as Quest Atlantis (Barab et al., 2011; Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007), River City (Dede, Clarke, Ketelhut, Nelson, & Bowman, 2005; Ketelhut, Nelson, Clarke, & Dede, 2010) and EcoMUVE (Metcalf, Dede, Grotzer, & Kamarainen, 2010) are showing the potential of MUVE technologies as teaching and learning tools. Given the promise of learning benefits such as enhanced motivation and engagement
attributable to media like three-dimensional virtual learning environments (3D VLE), MUVEs and serious games, interest is growing.

The majority of educational MUVEs focus on learners interacting within virtual worlds to complete learning activities and assume that all users will be interacting in the virtual world. However, the Holodeck@UH system we describe in this article allows students to be present both in the physical classroom and remotely in a virtual classroom. Our system is inspired by a prototype system developed by researchers at the University of Essex called MiRTLE (Mixed Reality Teaching and Learning Environment). In MiRTLE, a virtual world is connected with a real-world classroom to create the mixed-reality teaching and learning environment (Callaghan et al., 2008; Gardner, Gánem-Gutiérrez, Scott, Horan, & Callaghan, 2011; Gardner, Scott, & Horan, 2008; Horan, Gardner, & Scott, 2009). In pilot studies, researchers from the MiRTLE project found that virtual world (VW) and real-world (RW) students would naturally and spontaneously interact with one another, which caused the barriers of VW and RW to blur. Instructors reported that teaching in MiRTLE did not disrupt their classes or students’ learning. The implications of these findings were that using MiRTLE may increase the sense of presence for VW students, RW students, and the instructor (Gardner et al., 2008).

The purpose of this article is to provide a case description of early efforts in the design, development, and evaluation of our mixed-reality learning environment at the University of Hawai’i at Mānoa. The project is guided by a design-based research (DBR) trajectory and uses a technology system that was constructed using completely Free and Open Source Software (FOSS). The project was inspired by local challenges in facilitating collaborative learning at a distance. Higher education students in the Pacific islands are geographically dispersed and, given the distances between the islands, often perform their studies through online distance education. Creating an online environment to enhance social interaction and community-building at-a-distance for these students can often be challenging. Currently, a number of online course delivery options are used to provide these students with quality instruction at a distance, such as course management websites and web conferencing tools. Our best practices in distance education and our culturally-responsive pedagogies acknowledge and respect that our students value being able to celebrate community and connect socially with classmates and teachers. However, for students whose cultures value social interaction and building relationships, traditional online learning tools can feel inadequate. We have designed the Holodeck@UH to help bridge this gap. Our system, is designed to meet a unique and practical need through the use of a mixed-reality teaching and learning modality that “mashes” a 3D virtual learning environment with a real-world classroom. The case description we provide here outlines the design and development of our initial functional prototype and reports the findings from a formative evaluation study we performed on the working prototype.

The Holodeck@UH Mixed-reality System

The Holodeck@UH is a “mashup” that combines a real world space (a physical classroom where students meet in-person) with a virtual world (a three-dimensional multi-user virtual environment where students meet as avatars). We use the term “mashup” to mean a hybrid environment that uses technology to creatively mix elements of the real world and virtual world to create a unified experience. By providing two-way blending of the real and virtual world, learners are able to interact in both real and virtual spaces in ways that may be more natural-feeling and promote social interaction. Figure 1 provides a general illustration of this two-way connectivity.
With the Holodeck@UH, we meaningfully blend online and face-to-face interaction and collaboration, providing students with a deep social experience. Our design and evaluation work has advanced our understanding of how to design virtual places and associated instruction so as to enhance online learning. At the core of our design is the idea that students should feel socially present with others, whether they are located in the real world (RW) or virtual world (VW). By “socially present” we mean that students have a feeling of “being there” with others (Biocca, Burgoon, Harms, & Stoner, 2001). According to Horan and colleagues (2009) virtual worlds can enhance the community and social interaction between its users and provide a greater sense of presence than traditional online collaboration and communication technologies (instant messaging, chat, audio/video conferencing). Key to our design for enhanced social presence is creating high-fidelity representations of our students, whether they be attending class in the RW or VW. For our system, we combine immersive VW technology, voice over IP, high-speed networking and high-definition streaming video to create the mixed-reality experience. Local students attend class in a traditional classroom equipped with a high-definition projector, noise-canceling conference microphones, speakers, and a high-definition streaming web camera. The HD data projector is used to provide a view of the VW to those students who are physically present. From the perspective of the RW student, she enters the physical classroom, sits down, and is presented with a view of the VW on the projector screen at the front of the classroom. She is able to hear the avatars in the VW conversing and see them interacting with one another. The RW student may choose to log in to the VW and join the other students as her avatar, thus being present in both the RW and VW at the same time. Figure 2 provides a top-down schematic of our RW classroom. This represents one side of our mixed realities.
The VW classroom features three screens prominently displayed at the front of the virtual classroom. One screen displays a shared document that is used for collaborative note-taking by all students (real-world and virtual). Another screen displays the output from the high-definition streaming webcam, so that the students in the VW are able to view the RW classroom in real-time. The third screen displays the instructor's computer screen. Distance students attend class by logging in to a VW where they are represented as avatars, speak using microphone-equipped headsets, use avatar movements and gestures to interact, and interact with objects in the virtual-world using their mouse. From the perspective of the VW student, she logs in to the VW, navigates to the classroom area, and “parks” her avatar in one of the available seats. She is able to see a live streaming webcam video of his instructor from the webcam on his instructor’s computer. She is also able to see a HD video stream of the classroom and the students who are working there and is able to hear them speaking. Figure 3 provides an annotated screenshot of the VW with streaming webcam video of the physical classroom being displayed on a display. This represents the other side of our mixed-reality environment.
Free and Open-Source Software and Design-based Research

Free and Open Source Software is an approach to software development and distribution that includes source code and forms of licensing which permit ready customization and evolution while preserving the software as a common good. The benefits of using a FOSS VW platform are manifold. FOSS allows for ready customization and evolution to meet local needs, for iterations to meet special requirements of target users and for free access to source code. FOSS provides opportunities for designers, developers and users to participate in the community development effort that simultaneously contributes to meeting local needs (Carmichael & Honour, 2002; Lin & Zini, 2008). Open source software is particularly useful for educational application development in that it helps to establish a closer relationship between development communities, educators and users, so that the software can be iterated based on the needs and special requirements of the target users. The integration of the practices of teaching and learning with the flexibility and freedom to develop makes FOSS a suitable alternative to commercial software. Indeed, FOSS is gaining traction for its potential benefits over proprietary counterparts in the development of multi-user 3D VEs both for educational and enterprise applications. This interest is spurred by the flexibility, customizability and extensibility of FOSS 3D VE platforms such as Open Cobalt (http://www.opencobalt.org/), Open Qwaq (http://code.google.com/p/openqwaq/), Open Wonderland (http://openwonderland.org/), OpenSim (http://opensimulator.org/) and others. For example, Young (2010) discusses the decision to use the NSF-sponsored FOSS platform Open Cobalt over the proprietary Second Life platform due to educators’ lack of control of the proprietary environment. In Kappe and Guetl (2009), the researchers discuss development of a virtual conference room for knowledge transfer and learning purposes and their preference for FOSS software toolkits due to the ability to customize and add functionality to such virtual worlds as well as their ability to interoperate with other virtual worlds, including Second Life. Zutshi and Sharma (2009) compared the usability and acceptability of two proprietary platforms, Second Life and Qwaq Forums, and one FOSS platform, realXtend, for collaboration within an enterprise. While the authors reported success with the realXtend platform, they were unable to achieve their goals with the proprietary platforms. The authors note the flexibility of realXtend enabled building an environment that users found more consistent with their real work situation than was possible with the other platforms.
The MiRTLE project used the free and open-source VW platform Open Wonderland (http://openwonderland.org) to create their mixed reality classroom. Open Wonderland is a collaborative 3D virtual worlds toolkit for the creation of multi-user immersive VWs. Unlike other VW platforms like Second Life, which is an entertainment platform, Open Wonderland is built for deeply immersive collaboration and targeted at the education, business, and government sectors. However, Open Wonderland has limitations due to being a somewhat immature project. In our tests, we found it often to be unstable, to have poor performance with more than 15 avatars, and to frequently break due to Java updates. Because we needed a system that was reliable and consistent, these problems in testing led us to another FOSS VW platform called Open Simulator (OpenSim). We chose OpenSim due to its vibrant FOSS community, stability, ability to host multiple logged-in avatars simultaneously, and potential familiarity to prior users of the SecondLife platform. We found OpenSim to be highly flexible and to allow for a great degree of customization at a deep level. Indeed, OpenSim has gained a reputation of being very useful to educators. While choosing this technology, we considered the arguments made by the designers and developers of the MiRTLE environment, who noted that OpenSim was based on C# and .Net technologies, and therefore it was limited in terms of its cross-platform capabilities. Much had changed since the original development of MiRTLE, however. We found that OpenSim is able to run on Macintosh, Windows, and Linux systems, and even on Android. It is somewhat ironic that the very reason Open Wonderland was chosen for the MiRTLE project, that is, because it was based on Java, was the same reason we ultimately chose to move from that platform to OpenSim.

While the benefits of the FOSS approach for development of 3D VLEs are compelling, FOSS software solutions bring with them unique challenges. For instance, while FOSS allows for profound flexibility, it can also result in difficulties due to great diversity in implementations and the need for highly knowledgeable local staff that have the capability to participate in broader FOSS communities (Laffey, Schmidt, & Amelung, 2010; Schmidt, Galyen, Laffey, Ding, & Wang, 2010). Other researchers’ (e.g., Kappe & Guetl, 2009; Young, 2010; Zutshi & Sharma, 2009) note the high requirements of hardware and professional knowledge of the personnel in the implementation. This challenge could well be the primary impediment to implementing FOSS 3D virtual environments. Nonetheless, FOSS as a development methodology brings many benefits to designers and developers of instructional systems, particularly when instructional designers need to agilely revise, adapt, make changes and re-implement designs to fit the target context and adapt to unexpected or emergent contextual variables. Instructional technology both constrains and affords learning, as the unique tools and capabilities presented by the technology allow for novel and innovative learning approaches, yet the limitations and tradeoffs that are part of technology implementations circumscribe the range of learning activities which can be performed. How often do instructors desire that a software suite could perform a certain desired function or that it were easier to access certain functionality? When required design improvements necessitate changes to underlying software, such changes are typically not possible unless the software licensing allows for inspection and modification of the underlying source code. While the majority of purchased, off-the-shelf software does not allow for this, FOSS does.

The ability to enhance and evolve an instructional and learning system is of particular interest to researchers performing design-based research. DBR is theory-driven design, wherein the goal is not only the iteration of a product but also the advancement of a design theory for optimal learning and performance within a naturalistic context, usually in relation to the use of technology (Design-based Research Collective, 2003). In addition, DBR addresses specific, complex, and important educational problems (Reeves, 2006) by systematically testing designs in context with each implementation and analysis informing the next iteration of the design theory. It has been called an iterative cycle of design and enactment or implementation, followed by analysis of the implementation, theory iteration and redesign (Wang & Hannafin, 2005). These iterations of design and implementation have the goal of establishing the relevance of the implementation and ultimately its impact (Amiel & Reeves, 2008). FOSS seems to be a natural fit for DBR because it allows for maximum flexibility while iterating an instructional technology intervention due to its ability to be studied and manipulated at a very deep level, while at the same time promoting community and software for the common good.

Methods & Findings

Harnessing the power of advanced technologies so as to improve learning outcomes is complex and difficult. Researchers note that traditional research methodologies may be limited in their ability to connect technology-rich educational interventions with educational impact and point to design research (DBR) as an appropriate development and research methodology for technology-rich educational interventions that is focused on establishing their impact on real-world educational problems (Amiel & Reeves, 2008; McKenney & Reeves, 2012).
DBR systematically tests intervention designs in context, with each implementation and analysis phase iteratively informing proceeding phases (Wang & Hannafin, 2005). Reeves, Herrington and Oliver (2005) forward a series of principles for performing DBR which focuses on strong collaboration between researchers and practitioners and continual refinement of processes, questions and protocols. Because DBR embraces incomplete knowledge and allows for iterative expansion, promotes collaboration between researchers and practitioners and is well suited for technology-rich educational interventions, we have selected it as the methodological approach for our design, development and evaluation process. Following a DBR trajectory allows us to develop a robust product that is shaped by participant expertise, literature and especially usage testing. The design and research presented here represents the near-conclusion of one complete DBR cycle of analysis and exploration, design and construction, and evaluation and reflection.

A formative evaluation and usability study was conducted in October of 2013. The purpose of the formative evaluation was to explore perceptions of the Holodeck@UH among educational technology students and professionals. The purpose of the usability study was to examine perceived ease of use among educational technology students. The ultimate goal of this research was to test our designs, identify areas for improvement, and advance design principles. Research questions that guided the study were:

1. How do participants perceive the mixed-reality blending of face-to-face and online courses?
2. How do participants perceive social experience, sense of connection, and community in mixed-reality online and face-to-face modalities?
3. How do participants perceive the ease-of-use of the Holodeck@UH system?

An anonymous survey was developed using Google Forms, consisting of 20 questions, 15 of which were closed-choice and five of which were open-ended. The survey presented three short video vignettes of activities in the Holodeck@UH, after each of which participants were asked to answer questions based on what they had viewed. The survey was piloted with four educational technology professionals and amended based on feedback from the pilot. The research was also submitted to the campus institutional review board, which resulted in the research being given an exempt status. After piloting and IRB clearance a request to participate in the survey research was sent out to the University of Hawaii’s educational technology list-serv, with a follow-up being sent one week later. After one week, 40 participants had completed the survey. Participants reported their ages as 12% between 18 and 30, 37% between 31 and 40, 23% between 41 and 50, and 28% as 50 or greater. Reported occupations included teacher/instructor (44%), student (13%), technologist (23%), and other (20%).

For the usability study, a think-aloud method and a usability protocol “script” were developed using methods forwarded by Krug (2010). Participants were recruited by asking educational technology instructors for recommendations of students they perceived to be either (a) very technically proficient or (b) somewhat technically proficient. This was so that we would be able to recruit a sample with maximum variation in terms of abilities. Of four volunteer participants, two participants were chosen, both males, one of whom reported his technical abilities to be “very high” and the other of whom reported his technical abilities to be “pretty low.” The usability study took approximately 45 minutes to complete, including answering post-test interview questions. Participants performed a number of tasks in the virtual environment such as performing navigational tasks with their avatars and locating information. Participant interactions were recorded using screen recording, webcam recording, and eye-tracking.

A preliminary analysis of the evaluation and usability data was performed. Analysis of the evaluation data suggests that participants perceptions are generally quite positive, with participants describing the mixed-reality environment as innovative, engaging, and exciting. Participants report that using the Holodeck@UH could enhance the sense of community for students who are taking online classes on neighbor islands. However, participants also indicate that they would like to learn more about how the Holodeck@UH can impact learning, and how it would work in a real-world setting as opposed to video vignettes. Responses from non-demographic closed-choice questionnaire items suggest that participants find the mixed-reality modality to make the learning experience in the virtual world more personal, but agree that learning in mixed-reality appears to be complicated. Nonetheless, they agreed that mixed-reality seems like an engaging way to learn online and that our design could enhance a sense of community for students on neighbor islands. Nearly all participants agreed strongly that they would like to class in a mixed-reality environment like the Holodeck@UH; however, they also agreed that a mixed-reality system like the
Holodeck@UH should not be used to replace other online course technologies, but instead should be used to compliment those other technologies. These findings are presented in Figure 4 below.

The usability study focused primarily on the design of the virtual world, the ability of participants to locate the Holodeck@UH “classroom” area, and navigation in general. In addition, post-test interview questions probed the perceived overall usability experience. Analysis of the usability data suggests that participants’ perceptions of the environments' ease-of-use are positive, with participants reporting their experiences as “pretty easy.” However, a number of usability issues were identified. These usability issues are presented in Table 1 below. One identified usability issue stemmed from a lack of clear directions embedded in the virtual world to guide them to the areas they were asked to locate. However, both users were able to find the areas they were asked to locate in approximately the same amount of time and reported that finding the area was easy. In addition, participants were able to locate and activate the “screen” that presents the real-world classroom in the virtual world. They reported that this task was easy, that the view of the real-world classroom was clear and easy to see, and that zooming in on the screen and other areas of the virtual world classroom was easy. However, both participants had problems navigating their avatars up the stairs in the environment, with their avatars getting “stuck” and not being able to progress further. While our design provided for both ramps and stairs for navigating, participants seemed to naturally be drawn to the stairs. The more advanced participant quickly used a function to allow his avatar to fly in order to reach the intended destination, whereas the less advanced participant ultimately gave up and was unable to complete the task. In the post-test interview, both participants indicated a strong desire for more training and indicated that other users would likely experienced fewer challenges if given an appropriate amount of training. These findings suggest that while the Holodeck@UH is generally perceived positively and seems to have sufficient usability, more work is needed before we begin offering classes in mixed-reality. Findings from our preliminary analysis will help guide our next round of design considerations, and a more formal analysis of the data will guide our reflections as we return to our overarching design principles.
Table 1
General usability findings, usability issues, and suggestions for revision

<table>
<thead>
<tr>
<th>General Usability</th>
<th>Top Usability Issues Identified</th>
<th>Suggestions for Revision</th>
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<tbody>
<tr>
<td>• In general, participants rated the tasks they performed as “fairly easy”</td>
<td>• Insufficient visual cues in the environment for navigation</td>
<td>• Develop and implement “signage” for environment that both orients and guides the user</td>
</tr>
<tr>
<td>• Eye-tracking analysis provides powerful lens for interpreting participant perceptions and behaviors</td>
<td>• Some architectural elements invite actions that are not possible (i.e., stairs that cannot be climbed)</td>
<td>• With architectural elements, focus on function over form</td>
</tr>
<tr>
<td>• Using maximum variation sampling provided fast, meaningful results, even with n of 2</td>
<td>• Lack of training diminishes learner experience</td>
<td>• The value of training cannot be understated – in-world training sessions as well as just-in-time and on-demand support are needed.</td>
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</tbody>
</table>

Discussion

Findings from our formative evaluation study, as well as from the general process of designing and implementing the Holodeck@UH has uncovered a number of useful lessons that we feel are of value to virtual educators considering using Open Source VWs platforms for their own immersive education initiatives. As a consortium of educational technologists who desire to relate to higher education the values of the Free/Libre Software movement (an initiative that has been criticized for its sometimes idealistic nature) it is important that we remain practical in our evaluation of the technologies we implement. In this section, we attempt to provide a measured discussion of what we learned in the process of implementing Free and Open Source VWs toolkits. While Open Source VW software like Open Wonderland and OpenSim may not cost money, this is not the reason we opted to use these toolkits. Instead, it was due to the freedom that Open Source software affords. However, as readers will have learned from the history of our project (and to quote a former U.S. president), “Freedom isn’t free.” Implementing our system required skilled personnel with advanced expertise and skill. While our team is prepared for such challenges, we recognize that other VW educators may not have the necessary skills or time to invest projects such as this.

While the findings from the research presented here are positive and encouraging, they are limited by a number of factors. First, the study sample may not be representative of the users who will ultimately be using the system. A majority of participants identified themselves as teachers. We must question if a sample of primarily students would have provided different responses. In addition, participants were not able to actually use the Holodeck@UH or observe the system being used by actual students and teachers. Instead, they were presented with video vignettes of activities that are possible using the system. Some participants indicated in open-ended responses a desire to see how the system would function in a “real” instructional setting, and pointed out that without being to actually use the system, it was difficult to gauge the degree to which it is meeting its intended goal of enhancing social presence. Given the very early nature of our system, we view these limitations as challenges that should be approached in future iterations of our learning system and research design.

The Holodeck@UH represents an evolutionary step for the mixed-reality solution originally developed by the MiRTLE team at the University of Essex. We have adopted their original design ideas, built on them in unique ways, and implemented our derived designs in a different VW software system. As we continue to advance our project, we systematically test the designs and the underlying system in order to gauge its viability and usefulness for providing an online learning platform that enhances social presence. Moving forward in our DBR trajectory, we will build lessons for teachers who have agreed to help us pilot test the Holodeck with students enrolled in online courses, and to begin to implement learning analytics into the system to gauge how students are using it. Beyond that, we intend to field test the lessons we build in RW teaching and learning scenarios. The field tests will serve as opportunities to evaluate the Holodeck as a distance learning platform, to collect and analyze data using our learning analytics solution, and to develop expertise orchestrating instruction and learning in our system.
The interaction opportunities presented by mixed-reality are fascinating and have ramifications for hybrid learning. Providing an online environment that allows for seamless collaboration and learning between participants in the real and virtual world is compelling. However, more work is needed to understand how to leverage the affordances of a mixed-reality learning modality to establish educational impact. As we continue our design-based research trajectory, we endeavor to pursue this goal.

References


