Immersive Interactive Learning Labs for STEM Education

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Abstract: This paper describes using the digital dome theater as an Immersive Interactive Learning Lab (I2L2) for teaching K-12 STEM curricula. The I2L2 integrates several important aspects of education practice and theory for advancing shared 3D virtual environments as tools for inquiry and discovery learning. We describe our findings from different implementations of a new interactive game, the *Ghosts of Tikal*. Findings indicate that students' learning of conceptual information is enhanced in the I2L2 environment and that interactive games having a rich suite of content can readily be adapted to learners of varying needs and abilities.

Introduction

Immersive virtual environments hold great promise as tools for inquiry-based and discovery learning. Due to the enduring popularity of video games, 3D movies, and interactive virtual worlds, there is great interest among formal and informal educators in using immersive concepts and technologies for exploring a variety of subjects (Jackson *et al.* 1999, Johnson & Levine 2008). This interest has created a significant opportunity for a high quality interactive immersive platform that can be integrated into K-12 STEM curricula at a reasonable cost. Our goal is to investigate full-dome immersive interactive group games to facilitate students' learning of difficult STEM concepts and to determine best practices towards implementing such programs in the middle school grades.

Virtual environments that include social interactions in real time have been shown to be most effective in creating a sense of place, engaging learners in role-playing, and helping young people to learn how to collaborate (DeFreitas & Neumann 2009, Johnson & Levine 2008). By collaborating, students co-construct shared knowledge (Vygotsky, 1978) and help each other work through the learning challenges. A very important subset of educational virtual environments is interactive *games* (Squire, 2008, Kenny & Gunter, 2011) that allow for *active learning* in which students actively construct new knowledge and connect to their previous knowledge (Winn, 2003). With good pedagogical design, the game paradigm is a way to structure educational goals, activities, evaluations, and rewards in a familiar and motivating format (Jacobson, 2011). By creating interactive content and educational games for the digital dome platform (Apostoelellis, 2010, Sumners & Reiff 2002, Jacobson, 2011), we are bringing inquiry into the dome-learning environment while also advancing educational theory and practice in using shared 3D virtual environments as tools for inquiry-based and discovery learning.

A significant advantage of the portable digital dome experience lies in how students participate. Instead of just looking straight ahead, students look all around with freedom to focus on what they think is important. The wide angle view supports an inside (egocentric) view of places and objects revealing certain kinds of information in a uniquely useful way (Dede *et al.,* 1999, Jacobson, 2011). When participating in these games, students will be required to become keen observers of the virtual world that surrounds them and to make inferences about why things appear or behave the way they do. Students will also use critical thinking to develop an understanding of the bigger question that drives each game and to become independent observers in both virtual and real world experiences. The visually immersive format is exciting and engaging (Hunt & Worthen, 2006) which encourages and supports learning (Fraser *et al.*, 2010). This article discusses interactive games that we are developing for the portable dome environment as a new Immersive Interactive Learning Lab (I2L2) that engages learners by presenting concepts in an immersive virtual environment that replicates real experiences at times and in places that students cannot experience directly.

Development of Immersive Virtual Environments

The field of teaching in a digital immersive theater is quite young, since the Houston Museum of Natural Science (HMNS) opened the first digital immersive theater in the USA in 1998, followed by the Earth Theater at Carnegie Museum of Natural History (CMNH) in 1999, and now over 350 in operation. Research at HMNS using the video presentation of *Earth's Wild Ride* (Sumners *et al.* 2008), indicates that significant student content gains were achieved with exposure in the portable dome theater, particularly gains in conceptual understanding, rather than recollection of factual material. A step beyond the simple immersive video presentation is the *Temple of Horus*, a reconstruction of an exemplar Egyptian temple, which plays daily at CMNH.

The Temple supports individual and group exploration. In one version the single player explores each section of the temple until they collect enough information to answer questions and open the doors to the next. Another version of the temple serves as a virtual tour space, with a physical docent taking visitors on a tour of the virtual temple. The *Temple of Horus* was tested with students in both an immersive and flat screen environment. An evaluation study carried out by Jacobson (2008) compared comprehension of facts and concepts related to the Temple by students who viewed the presentation on a computer screen or in the immersive environment. Comprehension was higher in the immersive group, demonstrating that the immersive experience is an effective learning tool. Additional research showed that students who had lower scores on spatial reasoning tests showed greater response to the immersive environment (Jacobson, 2011). As an outcome of the positive results we observed using simple videos and a facilitated tour in the immersive environment, we wanted to extend the format with interactive experiences in which the audience moves around as if in a video game and interacts with the environment. For our study, we created two interactive experiences, *The Ghosts of Tikal* and *The Living Forest*. This paper discusses implementation strategies and results for *The Ghosts of Tikal* interactive game.

The game was developed as a feature-rich experience in which the audience has the freedom to move around anywhere in the virtual environment using a video-game controller. The game centers on a reconstruction of the Classic Maya city of Tikal in the Guatemala lowlands just before the collapse of the civilization. The free-form design of the program allows many levels of implementation for a group problem-solving game. Middle and high school classes may study ancient civilizations and already be familiar with the culture of the Maya, but for those students unfamiliar, there is an accompanying planetarium show called Mayan Prophecies. The show recreates Tikal and three other classic Maya cities and describes their collapse. The show can be used to introduce or follow the game experience. The show focuses on sustainability, the theme of the game. The playing area is large with 12 structures ranging from pyramids to huts in which students can explore while discovering 12 ghosts, each with a different role in Tikal society and a different clue about life in Tikal and why the city was abandoned. Treasures and animals found at Tikal complete the list of discoveries students can make. Sustainability components are integrated into the game such as a 4-hectare cornfield that would feed less than 1% of the population and manmade cisterns of all sizes for retaining water. Students also find no evidence of any beasts of burden or the wheel.

Ghosts of Tikal was tested using two group implementation scenarios depending on the preparation of the students and the available time. Scenario A requires more preparation and takes about twice as long to visit every location during the simulation. In both scenarios, the goal is a large group simulation, rather than a video game player and his audience. For this reason, the role of the pilot with the game controller is downplayed. The pilot has no power to decide where the group should go and must wait while others answer questions and make discoveries. There must be so much for the other students to do, that students don't want or ask to be the pilot. In like manner, the game cannot be a skill test for the pilot. Driving through the virtual space requires only 3 controls and is very straightforward.

Scenario A: Career-themed teams. In this scenario, students become Architects, Astronomers, Anthropologists, Ecologists, Engineers, Navigators, and Pilots who must answer different questions at each location. This game design is based on the teamwork paradigm of the Challenger Learning Center. Groups sit together as teams and collaborate in answering questions on the team checklists. This scenario comes with a complete teacher's guide for preparation before the scenario. In the ideal situation, students enter the simulation with their assigned roles and background on the Maya and the city of Tikal.

Scenario B: Career-themed individual assignments. In this scenario each student receives a small clipboard with images used for identification of buildings (the Architects), animals (the Ecologists), treasures (the Archeologists), and ghosts (the Anthropologists). Each ghost has an accompanying question that students must answer when they find the ghost. In this scenario, all students are ghost hunters and must identify where each ghost is, what treasures he has, and the clue he provides about life in Tikal. This scenario requires no advance preparation from the teacher and provides the teacher with summative activities when the students return to the classroom.

Game Implementation and Findings

HMNS has initially tested *Tikal* locally in Houston with different populations and achieved different results. Four examples illustrate the different experiences and the need for great flexibility in implementation depending on the students involved. Examples are in chronological order with adaptations implemented after each experience.

1) Fifth graders (Hispanic, inner city) with Scenario A: Students did very will with the scenario, but it was difficult to explain the career connection because of the language barrier. Also teachers did not have time for pre-visit activities. Teachers appreciated the interactivity, but needed more connections to tie student learning back to the classroom. Outcome: HMNS added a teacher's guide and instructions on assigning teams.

2) Sixth and Seventh graders special needs students with Scenario A: these students had been placed in a special school because of difficulty with classroom discipline related to shortness of attention span. Although the teacher told students about the scenario and assigned them to teams, these students could not handle the experience. It was too stimulating and they were not experienced with working in teams. This group did much better watching and discussing pre-rendered movies. However, five of the students stayed during their lunch period and were able to do the game. Outcome: Group size needs to be considered when working with students with special needs or different backgrounds; the instructor should be prepared to offer the backup Mayan Prophecies movie in case the group is not suited to work independently in teams.

3) Boy Scouts (predominantly going into sixth grade): These students were from different schools and did not know each other well. In this case, the desire to be the pilot was far stronger than to work as a team. For groups like this, a list of 12 challenges was developed (like jumping off of Temple 3 into the cistern) and students took turns being the pilot attempting the challenge and then watching other scouts. Although not the normal implementation, this procedure did work and students gained familiarity with Tikal and its architecture while having a good time in a virtual world. Students stayed engaged while other students tried to master the challenges. Outcome: The flexibility built into the game allows the instructor to take advantage of various aspects of the game to engage students with different interests and attention spans.

4) Sixth graders (Hispanic, inner city) with Scenario B: This group had no pre-simulation training. When they arrived at the dome, they chose an identification guide (for animals, treasures, buildings, or ghosts) and received a very brief description of their assignment. The teacher became the data recorder. The teacher selected the pilots from the students who indicated that they were good at action video games. Instructions were simple: (1) find the ghosts, (2) identify the building that each is in, (3) the treasures also in the building, and (4) answer the question posed by each ghost. The simulation was repeated with 3 groups and each time the students were engaged and the teacher was eager to record everything the students found. The teacher received a summary discussion activity to do with students back in the classroom and a description of how to extend the experience to other classroom activities. Teachers said that the experience was fun for the students and that the students learned important concepts. Teacher reactions were very positive and they did record all of the student discoveries accurately. Outcome: Engaging the teacher as an observer and participant may lead to additional learning potential for the students.

Conclusions

There were fundamental challenges we faced in the development of a full-dome interactive game. Technical issues were first and foremost and included issues in adapting the Unity 3D game development program to full-dome projection and production issues in creating a visually engaging environment at a reasonable cost. These issues have been solved and additional programs including *The Living Forest*, a virtual exploration of forest succession, are nearing completion. Pedagological issues outlined in this paper in developing a group interaction game that would engage a class of students for 45 minutes to an hour, be easy to implement, and meet classroom teaching goals, have shown a level of success, and additional scenario testing is ongoing. The pedagogy of a group simulation led to modeling the Challenger Learning Center process of group simulation. This process has been successful if there is enough preparation time with students. An alternative process is under development now for use with unprepared groups. Using this simulation in a teacher-directed manner is always successful, but it sacrifices a level of student interactivity. Finally it was observed that some groups did not have the mental discipline to participate in a group simulation game without extensive preparation. For this group, it is important to have a pre-rendered component that plays like a movie to calm down the students and introduce the simulation. Positive responses and suggestions from teachers for additional programs, particularly a simulation about the human body, make the I2L2 an attractive tool that advances the use of new technologies to engage large numbers of students in STEM topics.

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