My Dome:

Defining the Computational and Cognitive Potential of Real-Time Interactive Simulations in an Immersive Dome Environment

Summative Evaluation Report

November 2012

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LESLEY UNIVERSITY

Program Evaluation and Research Group at Lesley University

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Program Evaluation and Research Group at Lesley University

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Introduction

In August 2009, the Program Evaluation and Research Group (PERG) at Lesley University contracted with the project's PI at the University of New Hampshire (UNH) to evaluate *My Dome: Defining the Computational and Cognitive Potential of Real-Time Interactive Simulations in an Immersive Dome Environment*, an NSF-funded grant. The project focuses on creating interactive experiences in immersive virtual environments, and builds off previous work the PI and co-PIs have done in developing films and immersive experiences in domes and traveling domes. The project includes staff from the Carnegie Museum of Natural History (CMNH) in Pittsburgh, the Houston Museum of Natural Science (HMNS), and the Sasakawa International Center for Space Architecture (SICSA) at the University of Houston.

My Dome has two primary objectives related to the goal of creating immersive experiences (from the project proposal): 1) To conduct research on the opportunities for learning during real-time immersive experiences that will be designed for group interaction in the dome environment, and 2) To use the research findings to develop marketable immersive products. Through My Dome, a series of experiences have been developed and tested, including The Temple of Horus, an archaeological exploration of Ancient Egypt, and several other environments including a Northeastern forest, a moon base, and Tikal, a Mayan village.

Project Description

Over the (approximately) three-year span of My Dome, project staff developed and refined four immersive experiences: Temple of Horus, Ghosts of Tikal, Living Forest, and a moon base experience, which is currently being tested in Houston. Temple of Horus was created as part of a previous grant; through the My Dome project it was extended for viewing in a portable dome environment, providing it with the flexibility to travel to schools. The Temple of Horus takes viewers inside an ancient Egyptian temple, where they become immersed in the culture and architecture of the civilization. The show is led by a presenter, but is also interactive, as audience members are asked to participate and engage in some of the practices and customs of Egyptian culture.

The second production, Ghosts of Tikal, is a simulation of the ancient Mayan city of Tikal. This adventure is experienced in the form of a cooperative game, based on the design of the Challenger Learning Center Missions at HMNS. The ultimate goal of the experience is to determine why Tikal became uninhabited and what happened to the people who lived there. Participants can be grouped into different teams with different roles, including: Navigators/Drivers, Ecologists, Archeologists, Anthropologists, Astronomers, and Engineers. Each team has its own task list at a variety of locations throughout the city. The navigator and driver work together to interpret a map of the city and take the teams where they need to go using a remote control. At each location, one or more of the teams have to find an item or solve a problem, which are provided on a clipboard. See the Findings section for a more detailed description of Ghosts of Tikal.

The third experience, Living Forest, has been created primarily at UNH as a re-creation of a temperate Northeastern forest. In this simulation, primarily designed for the portable dome, users explore a small area of a forest, which changes over a simulated period of 50-100 years. Students can potentially take scientific measurements at various locations within the virtual forest, measuring the amount of light, biomass, and trunk size, among other characteristics. Measurements can be compared from the time of a young forest to that of an old one, extending the amount of data that can be collected in the field. This environment has been tested at schools in the Pittsburgh area, and at several schools and informal settings in New England.

The fourth experience, being developed at HMNS, is a simulation of a Lunar Colony. The environment is being constructed so that there are resources and supports to sustain a certain number of humans indefinitely. At this time, development teams are still working to determine what the participant interaction piece will look like when the environment is ready.

Project Activities

The following are project publications and presentations since the publication of the Year 2 Evaluation Report include the following (as reported by project staff):

Summers, C & T Butterfield, Shackleton Station: Exploring Sustainable Futures, International Planetarium Society Meeting, Baton Rouge LA, July 2012.

Summers, C, We Teach, but Do They Learn? International Planetarium Society Meeting, Baton Rouge LA, July 2012.

Handron, K, Schloss, A, Jacobson, J & L Ladwig, Virtual Forest – Student Directed Exploration in the Dome, International Planetarium Society Meeting, Baton Rouge LA, July 2012.

Handron, K, Schloss, A, Jacobson, J Virtual Egyptian Temple in a Dome, International Planetarium Society Meeting, Baton Rouge LA, July 2012.

Sumners, C, Schloss, A, Handron, K & J Jacobson, Immersive Interactive Learning Labs for STEM Education, P. Resta (Ed.), Proceedings of Society for Information Technology & Teacher Education International Conference 2012, p. 4894, 2012.

Schloss, A, Jacobson, J, &K Handron, Active Learning in a Digital Dome with the Living Forest, Immersive Education Summit, Boston, USA, June, 2012. (presentation)

Schloss, A, Jacobson, J, & K Handron, Active Learning in a Digital Dome with the Living Forest, Journal of Immersive Education, 2012. (publication)

Jacobson, J, Survey of Tools and Techniques for Sensory Immersion and Augmented Reality in Education, Immersive Education Summit, Boston MA, June 2012.

Sumners, C, Schloss, A, Handron, K, & J Jacobson, Immersive Interactive Learning Labs for STEM Education, Annual Meeting of the Society for Information Technology and Teacher Education (SITE), Austin TX, Mar 2012, http://publicvr.org/publications/Sumners2012.pdf

Evaluation

Evaluation activities and methodology

During Year 3, the evaluators continued to maintain frequent contact with project staff, particularly the Primary Investigator at UNH. An evaluator visited the Pittsburgh area in December 2011, and observed several showings of Living Forest to middle school-aged students in Beaver, Pa. In addition the evaluator observed other groups of middle school students who took part in testing Ghosts of Tikal at another school in Pittsburgh.

The evaluators used a number of methods and strategies to collect and triangulate the data, including observation of students in the immersive environments of Horus, Tikal, and Living Forest, brief pre/post surveys, informal interviews with several students, and interviews with participating teachers and My Dome staff.

During Year 3, evaluators did the following:

- Interviewed the project PI and co-PIs
- Observed students in immersive experiences in Greater Pittsburgh in December 2011
- Observed Living Forest at a school in Greater Boston in November 2011
- Participated in monthly telecons with project staff
- Reviewed and analyzed student pre/post surveys about Living Forest
- Reviewed student worksheets and surveys about Tikal
- Interviewed developers/designers of Temple of Horus and Living Forest
- Interviewed architecture students at University of Houston, who worked on the Moon Base experience
- Reviewed project artifacts
- Wrote summative evaluation report

Evaluation questions

The evaluation questions, developed in conjunction with project staff, consist of the following:

1) How do visitors interact with the technology? Which visitors benefit the most from the exploration of virtual environments? What age group, learning style, interests, and other demographics are best suited for these types of immersive experience shows?

2) Which tools and presentation techniques best facilitate the interactions with the show?

3) What challenges occur [for visitors and for the developers] in producing this type of show/immersive experience?

4) What is the ideal group size for these interactive experiences? How does the group aspect of the exploration affect an individual's experience (and do their roles within the group have an impact on their experience?)

5) How do the concepts, skills, and content presented in the shows relate to participants'

broader life experiences? For example: Does the Temple of Horus reinforce students' learning in the classroom? Do these interactive experiences spark students' interest in STEM careers?

While these original evaluation questions are, for the most part, still applicable, the focus of the evaluation has shifted slightly to accommodate the present needs of the project, and of each individual show/immersive experience. The evaluators collected data related to video game use and preferred learning style among Temple of Horus viewers, but did not collect similar data for the other experiences. Since the context of visitors' experiences varied between the experiences, it is difficult to draw comparisons between these products. Project staff and the evaluators did not have the opportunity to collect data related to students' interest in STEM careers, and the potential impact of these experiences on their interest in STEM. Finally, the Moon Base was still under development at the time of this report, and we do not have data from users.

Evaluation data

The following table presents the various data collected by PERG evaluators and (in some cases) My Dome staff over the course of our evaluation. The data collected in 2010 and earlier in 2011 was reviewed in the Year 2 Evaluation Report.

Overall	
Interviews with PIs	Individual, yearly
Participation in monthly conference calls	2011-2012
Interviews with developers	2012
Temple of Horus	
Observations (n=1)	Pittsburgh, 2010
Survey Collection (children & adults) (n=73)	Pittsburgh, 2010
Ghosts of Tikal	
Observations (n=2)	UNH, 2011; Pittsburgh, 2011
Surveys (n=52 pre/29 post)	Pittsburgh, 2011
Interviews with Teachers (n=1)	Pittsburgh, 2011/12
Living Forest	
Observations (n=3)	Massachusetts, 2011; Pittsburgh, 2011; NH, 2012
Surveys (n=122)	Massachusetts, 2011; Pittsburgh, 2011
Focus Group with Teachers (n=12)	2012
Interviews with Developers (n=2)	2012
Moon Base	
Interviews with PIs and Developers (n=3)	2012

Report

This report presents data and analysis over the three-year grant period and contains the following sections: Introduction; Evaluation; Findings, and Discussion/Summary. An appendix with the interview protocols follows this report.

Findings

As noted in the Introduction, My Dome focused on the creation and refinement of several virtual reality/immersive experiences for dome settings. In this section of our report, we summarize the data collected on each of these experiences—Temple of Horus, Ghosts of Tikal, Living Forest, and the Moon Base.

Temple of Horus

Overview and viewer response

The Temple of Horus, modeled on an Egyptian temple, was created through an earlier grant and refined/further developed through My Dome. Most of this work took place during the first year of the project, as described in the Year 2 Evaluation Report.

PERG evaluators worked with staff at CMNH in Pittsburgh to collect data from youth who viewed the show in either an inflatable dome or on a panoramic screen in the Earth Theater at the museum. Staff collected data from a sample of students, looking at content questions related to the show, and student engagement. The evaluators compared variables such as frequency of video game use, and the viewing environment –- full dome vs. panoramic screen.

At this point the Temple of Horus has been fully developed and is currently showing at CMNH. Evaluation data indicates that the majority of youth audiences in the Temple of Horus show were engaged and enjoyed the experience, would recommend it to friends, and were able to answer some simple content-based questions after viewing the show. Participants viewing the show in either the dome or the (panoramic screen) theater provided similar responses on surveys for most questions, and there did not appear to be any significant differences based on student video game use or type of learning preference.

The Temple of Horus is an example of a presenter-guided experience that provides historical, cultural and architectural information to an audience while making connections to the modern world. This show can be viewed by both youth and adults in public settings, or during school visits in the portable dome. For a full analysis of key data, please see the Year 2 Evaluation Report.

Effective presentation and future use

My Dome staff indicated that Temple of Horus is aimed primarily at middle school students, though the experience could (and did) engage younger and older children and adults, particularly if they were interested in Ancient Egypt. One staff member called Horus a "mediated world," since viewers do not drive/take the controller, but are guided through the experience. Because of the less interactive format (in comparison to experiences such as Tikal and Moon base), larger groups can be accommodated.

> *If the group is coherent, like 7th graders from same school, even a large group can be effective, up to 50 [students].* *(Project staff)*

One developer of Temple of Horus described the broad audience he hoped to impact, the ways in which the show could be adapted to individual audiences, and the flexibility of using a virtual reality temple rather than a real structure.

> Who was your primary audience? *The average everyday user, we put on shows in galleries and also for the Carnegie Museum of Natural History in Pittsburgh in an active VR room. Students, adults, anyone who is interested to see what it would be like to be inside a temple. You can't really reconstruct a temple to walk around in without a large budget, and it's stuck [can't move].....for Temple of Horus, it [the challenge] was picking a topic that had value and interest. I'm not sure anyone had done a virtual reality ceremony before....* *(Project staff)*

One staff member emphasized the importance of engaging the audience for Temple of Horus by using effective presentation techniques and improvisational strategies; the quality of the presenter affects visitors' experience in the temple.

> *Before a presenter-mediated experience like Egypt, I've discovered the field of improv acting and how to use concepts like status in engaging everyone in the audience in the program. There is a whole field that has a lot to teach us in creating good presenters. Before I thought some people are just good presenters and they can adjust presentations quickly but now I'd say there is someone [instructors] and a field that teaches people how to do that....that's a result of this project, I was able to attend a couple seminars.* *(Project staff)*

Another key factor in facilitating visitor learning and engagement is providing visitors with sufficient time to view the temple, as noted below.

> *Having a good presenter, who engages with the audience, with the temple you have to give people time to look around, and people absorb visual information at different rates. The audience needs time to see everything and put together a visual map, so filling time with auxiliary information and having extra information to fill in [is key for visitor engagement/learning].* *(Project staff)*

Going forward, project staff said that the Temple of Horus could be used for many years, and that it dovetails with various state standards related to social studies and history.

> *Egypt [Temple of Horus] clearly fits Pennsylvania and Massachusetts state standards....comparing and contrasting cultures and understanding contributions to society. Social studies standards include being able to take lines of thoughts and synthesize and develop one's own thoughts, that's in Egypt and we support that [process.]* *(Project staff)*

One of the My Dome developers described the impact of Horus, and the importance of maintaining interest throughout the immersive experiences, particularly for youth.

> *I'm always impressed with the full view, it grabs the kids. Like coming in and seeing the Egyptian temple and the wall around them, it grabs their attention. For a group, how do you keep that [level of engagement] going for the length of a program? We improved that as we went along. We knew people make more connections in immersive [environments] than flat screen but how do we support the right or most effective connections? We got better at that as we went along.* *(Project staff)*

Ghosts of Tikal

As noted previously, Ghosts of Tikal is a simulation of an ancient Mayan city. This adventure is experienced in the form of a cooperative game, based on the design of the Challenger Learning Center Missions at HMNS. The ultimate goal of the experience is to determine why Tikal became uninhabited and what happened to the people who lived there.

Overview and user response

Ghosts of Tikal was developed by one of the Co-PIs at HMNS, and tested at all three sites. My Dome staff tried a variety of approaches and worked with school groups and in informal settings. One constraint mentioned in the Year 2 Evaluation report was time –- students' academic periods are often less than one hour, which may not provide sufficient time for them to experience Tikal. Key factors that may influence the relative success of Tikal in terms of student learning and engagement, adapted from the Year 2 report, are listed below:

These factors included the following:

- *Driving the game*—this sometimes resulted in a struggle for control and competing demands to visit various places in the game;
- *Communication and teamwork*—Students were often unclear of their roles, and some had little to do, while others were more engaged;
- *Content knowledge and background*—Without some type of orientation, students were sometimes unclear about the context of Tikal. Those who viewed the film, "*The Mayan Prophecies*," appeared to have more understanding of Mayan culture and the setting of Tikal;
- *Questions and tasks*—Participants were not always clear as to why they were doing various tasks, such as looking for various objects, and why key activities took place at Tikal;
- *Group demographics*—Group size was a key factor in determining student engagement. Larger groups often included students who became distracted, while smaller groups could be more focused, and age was also a factor;
- *Time*—As noted above, it appeared difficult to guide students through Tikal in less than one hour. The co-PI in Houston has developed a variety of ways of presenting Tikal in both formal and informal settings, and has reported success in engaging youth by incorporating more learning elements directly into the game;
- *Facilitator*-–Facilitators ultimately need to be well-acquainted with the game, so they can guide participants to the correct areas when necessary, and answer questions about both the environment and the Mayan culture. This may be a challenge in the future when the game is disseminated beyond the program developers.

Implementation and testing

Ghosts of Tikal has been developed at HMNS, and tested at all three primary locations, in Houston, Pittsburgh and at UNH. A PERG evaluator observed testing with 6th, 7th, and 8th grade students at a school in Pittsburgh in December 2011. Fifty-two (52) completed pre-tests and 29 provided post-tests after viewing the *Mayan Prophecies* video and experiencing the Ghosts of Tikal. During this testing period, as many as 30 students were in the dome at one time. Comments from the teacher (see below) indicated that both the students and teachers needed some preparation and orientation before they took part in the experience. The post test results did indicate that many students learned something new from the video and Ghosts of Tikal. On the pre-test, 15 of 52 students (29%) incorrectly identified the Aztecs, Inca or Sioux as residents of Tikal; after viewing the video, only 1 student answered incorrectly.

In a similar vein, before watching the video, 23 of 52 (44%) of students said that Tikal was in South America, Europe or Africa; after seeing the video only 6 of 29 (22%) gave these answers. (The rest correctly identified Tikal in Central America).

Finally, 41 of 52 (79%) gave incorrect answers to the survey question, "What happened to the city of Tikal?" citing war or disease as the cause of the city's demise on the pre-test. On the post-test, 24 of 27 (89%) correctly cited drought and famine as the reason for Tikal's decline.

It appeared that most of students' learning took place while they watched the *Mayan Prophecies* video rather than in the Ghosts of Tikal, as reported by five students who spoke with one of the evaluators informally after this experience.

Note: Some students were in Ghosts of Tikal with a group of kindergarteners in a buddy-system arrangement, which was not successful in promoting student engagement; the combination of younger and older children in the dome added to a sense of confusion, as reflected in some of the comments—from a group of 7th and 8th grade students—below:

> *I was an ecologist, trying to find the animals with little kids, I wouldn't allow the little kids, they yelled. It was hard because the pilot didn't stay in one place for more than a few seconds….I Learned a lot from the video **?** I thought the movie was really good, graphics, and going down into the tomb and seeing the dragon in the sky.*
>
> *(student)*

> *I didn't like it with the Kindergarteners, [but] I thought it was fun, I learned more about the Mayans, about the culture, how they lived, they sacrificed people…I didn't know that before.* *(student)*

> *I thought the calendar was cool and how they estimated the end of the year…..[Kids talk about how they heard about end of world and everyone is talking about it.*
>
> *(student)*

Presentation and future use

The factors previously identified, including the size of the group and the age of participating youth appeared to influence their experiences in Ghosts of Tikal. My Dome staff reported that the game is still "a work in progress" as reflected by the comments of one teacher in Pittsburgh, who guided her students through the experience in December 2011. This teacher highlighted the educational potential of Tikal in school settings, and suggested the following:

- Limit total number of students in the dome to 16 and have them work in pairs
- Prepare students by giving them the pre-test several days in advance, before they apply for their various roles/jobs
- Have students meet by roles, and then by teams to prepare for Tikal
- Show students the introductory video about the Maya, and then allow them to enter the dome *several* times—first with an experienced driver to enable them to locate key information
- Have a recorder for each role, and make sure students understand what they are seeing before moving on to the next location. This would allow each student to work with a partner
- Overall, students need some *preparation* for Tikal, rather than having them "go in blind" without orientation or an understanding of the primary tasks/challenges built into the game

Currently, the Tikal experience is being used at camps and in informal settings, where youth enjoy "falling off pyramids" and exploring the sites within Tikal.

> *Meanwhile we're looking at what kids enjoyed about playing the game. They liked finding things. Finding treasure worked, but even better was falling off the pyramids – jumping 24 meters, adding the jump function which was done at a whim by our teenage programmer, jumping up the pyramid, all of that, suddenly it was a lot more fun, making the kids enjoy it more. I'm still considering Tikal a work in progress. We're distributing it this year as Ghosts of the Maya because no one knows what Tikal is – taking it to camps, we used it in the summer with kids. (Project staff)*

Challenges

Data indicate that if Ghosts of Tikal will be used in schools, more work must be done to allow teachers and students to orient/prepare themselves for their experience in Tikal, as reflected in the comments below.

> *One thing with Tikal, it didn't specifically fit standards, teachers liked it but it was hard to get them to bring it into the classroom, that's one thing if you're doing formal education. We're talking about making it more like video games they [students] play at home but adds the feeling of being in a place, that takes you someplace you can't go but what do you do with that experience—that's what we were trying to tease out. (Project staff)*

> *According to My Dome staff, the game continues to evolve (primarily in Houston). One challenge has been to connect Ghosts of Tikal to various state curricula. One staff member discussed this challenge, and various iterations of the game, and noted that revisions are continuing. So we're trying to figure out how to keep it going, connect to*

curriculum and make it run. With curricular part it was obvious that these 4-5th graders [in Houston] who were 50% Mayan, never heard the word, never studied it – didn't help us because we had to find a grade level where they were studying it, which is 6th grade world history. Or connect with sustainability or the environment, so we built that cornfield and huts. [That] gave us a way to talk about how many people you can feed…. It's [setting up] this product to go into another grade level besides history. I think that will work. We never got the curricular component where we wanted it. *(Project staff)*

The Living Forest

Overview & Implementation

The development of the Living Forest began during Year 2 of My Dome, and the experience continued to be tested and refined throughout Year 3. The Forest is a re-creation of a temperate New England forest, and engages users by exploring an area containing various species of trees, which can grow over a simulated period of 100 years. This provides students the opportunity to observe and measure the same section of forest over a period of time that would not be possible in the real world. Living Forest contains tools which allow students to take scientific measurements at different states and locations within the plot, including measurements of light, biomass, and trunk size. The ability to collect and use this data in the virtual forest will help students better understand more complex concepts such as forest succession and the carbon cycle.

Of all of the interactive experiences created during My Dome, the Living Forest has the clearest connections and potential uses in formal education. The measurements and data taken from within the dome can often also be taken outside in the field, and the similarities and differences discussed. The concepts explored during the Living Forest, can also be adjusted to various grade levels and skill sets. Younger grades (late elementary into middle school) can use the experience to observe changes in the Forest, identify species using leaf and bark patterns, and start to quantify changes in light (i.e. more vs. less) over time. Those in the higher grades can take more specific measurements, graph changes over time, and use statistics to measure these changes. Data can also be compared to data taken from live forests in the field.

The purpose is to show something impossible to show in real life, to show development of land over a hundred years, to go through the steps and see how everything develops, and stages of growth. *(Project staff)*

Development and challenges

By the time the Forest was being created, project staff had gained considerable experience through the creation of Tikal and Temple of Horus, and had an understanding of what works and doesn't work as far as controllers and projection within the dome. The Forest does not require the same kind of technical driving skills needed in Tikal, as the emphasis is more on measurements and observation than exploration.

The creation of The Living Forest required both technological and coding skills as well as intricate knowledge of the features of a temperate forest. Those working to create it had to collaborate to become familiar with both aspects of the experience.

One of the other interns I worked with at start of the project, he was more involved in the environmental accuracy than coding, so we collaborated and he brought me on a walk in the forest and talked about different types of trees and how they changed over time. He taught me, and I think that was the goal, to teach those same types of things to users. *(Project staff)*

One of the challenges to the development of the Forest was the detail with which the leaves and trees were created. Project staff hoped to make the images appear as realistic as possible, however due to time and budget constraints, there was only so far they could go in that direction. Recently, there have been discussions about the benefits of making a more cartoon-like/less realistic appearance, since the project budget and resources are somewhat limited.

Implementation and use

The Living Forest was shown to two 5th grade classes (~43 students total), in Stoneham, MA in the fall of 2011. It was also used with 3 classes of 6th grade students in Beaver, PA. Evaluators were present at each of these sites to observe and collect student surveys. A portable dome was brought into the gymnasium and each class had a chance to experience the Forest, led by a facilitator from UNH (MA), or CMNH (PA). Students were given lighted clipboards with a guide to identifying different species of trees based on their bark and leaves. Once inside the dome, the facilitator introduced students to the environment, and drove the group to various trees to talk about species identification. It is possible to have a student or the facilitator drive, depending on the needs of the group. Students visited multiple trees, and recorded what types of trees they saw at the earliest growth stage of the forest. The driver then pushed a button, which moved the entire forest ahead in time by 50 years, and then later up to 100 years (mature forest). At each of these stages the group continued to identify types of trees present, their number, and made observations about the amount of light and the "feel" of being in the forest at each stage. The Living Forest also can switch to winter mode, where similar observations can be made. At the time of these showings, the measurement tools were still under development, so evaluators were unable to see them in use. (The light meter tool did not work reliably during the course of our evaluation).

Results

Students

Observations of the Living Forest indicated that most students were engaged and on task. There was initial excitement and chatter about being in the dome and a sense of being immersed in the forest as it grew. During observations at both schools, time was limited to a single class period; about 30-40 minutes was available for each group. This felt rushed, and didn't allow the students ample time to adjust to the environment, nor give the facilitator an opportunity to give a full introduction to the tasks and the concepts being explored.

Students were given pre and post surveys that explored their familiarity with forests, as well as some content-related questions. (See appendix for surveys).

Students	# of survey respondents
Mass (5th grade)	76
Penn (6th grade)	42
Total	**118**

The first question on the post-experience surveys asked students, "What did you like most about the Living Forest?" The majority of students wrote that they liked seeing the forest grow, being in the dome environment, being able to move around the forest, and learning about different types of trees.

The following are representative quotes from students:

How the pine trees keep their needles in winter

I liked how trees grew over a period of time and it made impact on growth of some trees

It was very realistic, the graphics and dome made it seem real

Having to identify the trees and being in the dome so it felt like we were there

I liked the dome shaped projection because it made me feel like I was in the forest

Surveys asked students to list three types of trees that they know live in their home area. On pre-surveys, the majority of students named the same types of trees--maple, oak and pine. On post-surveys, while these types still made up about half of the trees listed by students, their responses became more detailed, and some students added new types of trees. For example, instead of "maple," students often wrote "sugar maple." And instead of "beech," they used "American beech." Other new species on the post surveys were pin cherry, eastern white pine, and birch trees.

Surveys also asked students to give three reasons why they though forests were important. About three-quarters of students were able to provide two or three answers on the pre-survey, the most common being for oxygen, shelter, food, or paper. The same question was asked on the post survey, without any significant changes in response. This could be because most 5th and 6th grade students were already aware of these important attributes of forests.

One of the main learning goals of the Living Forest is to help students to understand changes that take place in the forest over time. One survey question asked students to check off all of the things that would take place as a forest ages. Students in both MA and PA improved their correct responses from pre to post, particularly related to the idea that branches get longer and wider as a forest grows. Students in Massachusetts also improved their understanding that different types of trees are present at different forest stages. This improvement wasn't as strong in PA, where fewer students answered correctly on the pre survey as well.

The following table shows the percentage of students who answered "yes" that various changes take place in the forest as it ages.

% answering "yes" this happens as a forest ages.	MA (n=44)		PA (n=78)	
	Pre	Post	Pre	Post
Trees get taller	90%	100%	76%	82%
Different kinds of trees start to grow	59%	71%	36%	40%
Branches get longer and wider	76%	90%	64%	81%
More sunlight reaches the ground (false)	12%	7%	16%	15%
Tree trunks get wider	76%	88%	72%	78%

Another major goal was for students to increase their understanding of the differences between deciduous and coniferous trees. Once again, the percentage of students answering correctly increased in both locations from pre to post experience in the dome.

% answering "yes" this is a difference	MA (n=44)		PA (n=78)	
	Pre	Post	Pre	Post
They have different types of bark	60%	88%	53%	62%
They live in different parts of the world (false)	33%	24%	32%	21%
One loses their leaves/needles every fall and the other keeps them	50%	71%	73%	77%

The concept of forest succession is most central to the design of the Living Forest, and one of the key aspects of forest succession is that as a forest grows, less light comes through the canopy to the forest floor. Surveys before and after the experience asked students to indicate if they think more or less light reaches the floor as the forest ages. Prior to the show, more than half of students answered correctly (less). After the show, the percentages increased in both locations, with more than three-quarters of students answering correctly. This indicates that the Living Forest was successful in helping students understand the way that light in a forest changes over time.

The following table indicates the percentage of students answering the question about light in the forest correctly, before and after the show.

	Pre	Post
MA (n=44)	71%	93%
PA (n=78)	64%	81%

Teachers

Teachers in New Hampshire had the opportunity to experience Living Forest during a UNH workshop in the spring of 2012. They were taken through the experience as students would be, and then evaluators had a chance to discuss the experience with them. Overall, teachers believed Living Forest had educational value. Most said they thought it would be particularly effective as a training tool/introduction to some of the concepts they would

reinforce in the real forest, such as succession, tree canopy cover, and seasonal changes. They wanted more tools—to make the experience more engaging and worthwhile for their students. One key concern focused on the logistics—if and how teachers could arrange for all their students to see Living Forest in the dome.

I like it as an engagement tool, so students think of changes over time—that's something we can't do in the field. (teacher)

This is a good first pull about what is changing…a big part of the biology curriculum [deals with] succession and what is changing over time. (teacher)

Teachers also discussed some of the logistical benefits offered by the virtual environment the Living Forest presents.

It's much more controlled...you can plan a day to be in [the dome], that day shouldn't change, no weather factors or other things that occur…I get outside a lot but it's hard to get them from point A to point B…it eats up 45 minutes very quickly. This activity would be a primer for that. (teacher)

Another teacher pointed out the benefit of having the dome for a student with medical issues, who could not go outside to collect data. This would enable her to have a comparable experience while her classmates were in the field.

I have a student with severe medical needs and her mother was very nervous about having her go outside so something like this is really good for providing a comparable experience for kids who can't go out in the field for whatever reason, knowing that this is a resource, I don't have to abandon fieldwork, I know I have this [experience] for this student while the rest of us are doing fieldwork. (teacher)

This conversation with teachers also provided some practical suggestions for improvement of Living Forest. Teachers suggested the addition of more measurement tools such as a light meter, compass, and the ability to label trees, manipulate the weather, or have a virtual field guide. The teachers were also identified many different ways they could potentially use the Forest with their students, often paired with field work. While they could see ways to fit the experience in with the curriculum, they did suggest that there be some clearer learning goals that would be presented with the show. These objectives would help teachers know what to expect, what concepts were going to be covered, and what orientation/pre-experience activities they could do in the classroom.

Moon Base

The Moon Base, the final experience to be developed through My Dome, is currently being tested in Houston. Using the ideas and basis from a NASA-developed International Space Station simulation, a model of a lunar colony, and a detailed map of the moon, the Moon Base developed into an interactive, simulated environment of Shackleton crater. Graduate students in the Architecture program at the University of Houston were recruited to do much of the technical work of designing and programming the game in Unity. According to the students, their involvement in the creation of the Moon Base was challenging, educational, and impacted their career goals.

The biggest challenge was learning Unity 3-D program and incorporate our skills as designers with the other three programs, first challenge was to master the program, nice skills to have. (My Dome student developer)

After working on this project, I included some of the design process and thinking into my thesis paper and it was presented at a conference. (My Dome student developer)

[The dome environment] makes the design process more challenging, especially in color choice, something may look good on screen but washed out on dome surface, colors can look washed out, need to go for contrast. (My Dome student developer)

The moon base colony is designed to sustain life for 80 people. The design incorporated everything needed to sustain life, including medical needs, fitness, food, facilities, and other resources. Throughout development various features have been changed, added, or updated as more users have tested out the experience. The most notable of these was the addition of a truck, which serves as the vehicle in which participants will explore the environment. According to the co-PI/lead on this project, this addition grabbed the attention of students, as they initially have to grapple with learning how to drive the truck in a rugged environment with no gravity. Using the truck, a facilitator sends users on missions around the crater, delivering cargo to one location or another, finding and visiting the ice mine, solar telescope, or the rim of the crater. Groups of students can take turns driving, and PI observations indicate that even those not currently driving the truck are engaged and entertained by helping their peers drive; often making observations about the unique environment, scouting out features to visit, and helping the driver keep the truck on the path.

They can take cargo up to the rim of the crater or explore a solar energy farm, melting plant, or see the South Pole of the moon, drive there, and use a solar telescope. That warns colonists of solar flare. If they go down they can go to the colony, and if you want to reward them they you can let them zoom in and see the colony from the cupula. Then beside it there's a miner, they crawl down into the crater and mine the ice and pump it back up. (Project staff)

The Moon base has many potential connections to late elementary and middle school curricula. These include concepts surrounding sustainability: (what does it take to sustain life on the moon?), technology, gravity, properties of the moon, and math skills needed to make many calculations essential to life on the moon. The co-PI believes that students who are immersed in this environment through playing the game will walk away knowing more about the moon than those who do not have that experience. The use of a facilitator or guide, who can tell users about what they are seeing in the environment and provide new missions or challenges, also makes the Moon Base game customizable to various age groups or curricula. By the end of the grant period, the Moon Base was just finishing development, and evaluators were unable to collect data about participant experiences.

Staff Research and Learning

Key Factors for Immersive Experiences

More than anything I learned about getting a group of kids together and getting them doing stuff all together based on particular curriculum and the virtual environment. There's a paradox of interaction with a group in virtual reality, if you have a group, you want them to interact, but how? The larger the group, the harder to single out individuals. I've gained a wealth of new ideas how to do it, classroom and field trip activities that can be adapted. (Project staff)

The research focus of My Dome has enabled project staff, including the experienced developers, to expand their understanding of visitor learning in dome/virtual reality environments, and the potential benefits of these environments.

One thing I learned, it really clicked when I saw it, the purpose of the dome is to change the perspective of the learner more than teach them a lot of things….You can't get someone excited about content without showing them content and making it come alive and get excited, a dome is great to do that for certain topics….I like that My Dome and this team is experimenting with different things, different approaches. (Project staff)

Most people don't experience a fully immersed environment, that's an interesting, dazzling experience, it allows them to be somewhere they couldn't be….you could go to a forest but you don't have time machines to travel to the future [see change over time]….It's generating an environment that can be changed. (Project staff)

One of the respondents quoted above stressed that using immersive dome experiences as learning tools is a new phenomenon.

The informational design and communication design of domes is a new thing, except for astronomy….we know how to do star shows but everything else we're just doing the first sketches…..we can create something not readable and [we're still] finding what engages the kids and what doesn't. ? We're at the very early stages of using this tool of using fully immersive visual environment for active groups. (Project staff)

In addition to the benefits of engagement in an immersive dome, project staff learned about specific aspects of these immersive experiences, including the factors of type of learning environment, background knowledge, group size, and role of facilitators. Each of these factors played an important role in the development of each of the four experiences created during the My Dome project. However, each show is unique, and requires a unique combination of these factors in order to maximize the learning experience of users. There does not appear to be one best way to engage an audience.

Formal vs Informal Learning Environment

My Dome staff also identified some of the differences between formal and informal learning environments, and how those environments influence participants' interactions with immersive experiences.

I think it's different if your audience is formal education vs. informal audiences. For informal, I think it's easier, you know you have them [visitors] for a limited time, you're trying to get their attention, interest and excitement, if they get nugget of information on whatever the topic is, [the experience is successful]. But in a formal

environment, you have to be much more specific, fit in teacher's time [periods] and be very precise in what you're doing and how you engaged the kids. It's much harder than I anticipated in doing an interactive show. A film has to be engaging but they'll [students will] watch it but creating something interactive [for students]….and then have them give back knowledge and engagement, I found it kind of tough.

(Project staff)

Of the four My Dome experiences, Temple of Horus is the most suitable for a museum setting with different groups of visitors passing through. The Temple does not require participants to collaborate with each other to solve problems, nor does it require much context or background knowledge. However, it would also be suitable for school groups studying Egypt. Ghosts of Tikal and the Moon Base are unique in that they require users to work together to navigate and solve problems, often over an extended period of time. This would be difficult (but not impossible) to implement into a museum exhibit for the general public, or to use in a formal educational setting with time constraints. These experiences would likely work best with informal learners who have time and flexibility to work together over time to fully engage in the game, such as scout groups or summer camps. The Living Forest is the most suitable for formal education, as it fits well into school curricula, and is more directed than the Moon Base and Tikal. While it hasn't been tested, the Living Forest could possibly fit into a museum setting.

The [living] Forest fits better in a formal setting, partly because the way the story falls out, it's clearly connected to stuff they are supposed to be learning. And interest in topic [is key], more people are inclined to want to learn about Egypt, that makes it stronger for informal [settings with] kids and adults….Tikal…is not really set up for very young or adult audiences. Also in Forest and Tikal, adults feel more motion sickness….Egypt [Horus] is most effective for adults and mixed audience.

(Project staff)

Context & Background Knowledge

Another factor related to user learning involves placing these immersive experiences in context. Depending on the setting, users may come in to the experience with a range of background knowledge about the topic at hand. Especially for the Ghosts of Tikal, an introduction to the Mayan culture and story is essential to engage students in the missions of the game. This was accomplished by showing the film *Mayan Prophecies* to some groups prior to their dome experience.

For the Temple of Horus, Moon Base, and the Living Forest, having an experienced and knowledgeable guide is essential to the experience of participants, however extensive background knowledge is not as crucial.

Discovery Dome Network markets these but I think an educator should come with these. I think that's a big gap….need someone with expertise. Need to place the experience in context, not just a 'one off'……that gives someone to bounce off of, if they get excited they could talk to person about the equipment and the content, to not just see it and talk among themselves. *(Project staff)*

It is necessary in formal settings to connect the experience to the curriculum. Ghosts of Tikal, in particular, did not easily fit into curricula. In addition, learning goals needed to be refined and clarified, and teachers/students needed some orientation to the experience in order to enhance learning in the dome, as noted in previous sections of this report.

You could film a walk through or a desktop version….[co-PI in Pittsburgh] made a few walk through videos so teachers could see an example of how it looks, of what it would be like, not in Dome but gives them an idea…that would be a big help to have a demo capability. *(Project staff)*

Group Size & Engagement

Staff also discovered that ideal group size, age, and other characteristics varied among the experiences. For example, a large group of 40 or more could be accommodated in Temple of Horus, but the Ghost of Tikal more suited to small groups (ideally under 15).

Related to group size—I think it depended on the program. The way we set up Tikal, a large group was more problematic. We set kids in teams, that was good, but at times there was not enough for some teams to do, that was a problem, you have to set things up so kids have things to do or they get bored and lose interest. With [Living] Forest I think we did OK because we had everyone trying to identify the trees….but I learned you can over plan or try to do too many things, and we had to cull that down. *(Project staff)*

While yet to be tested, the Moon Base will also likely work best with smaller groups, which can collaborate and take turns at the controls. Larger groups may lose the interest of those who are not driving. The Living Forest may work with larger groups than Tikal and the Moon; however fewer students than Horus would be ideal. Participants in the Forest experience can all record data and practice identifying trees, regardless of who is driving.

Another related challenge centered on the level of realism represented in the My Dome experiences. Some teachers and students (particularly in Living Forest) were distracted by aspects of the virtual forest—such as the lack of clarity/lower resolution of trees and leaves. One project staff member wondered if making the images somewhat but not fully realistic led to some frustration on the part of viewers.

There are some issues and criticism that it's [Living Forest] not real enough, you can't see individual leaves so clearly. It makes me wonder…research showed if you represent something like stick figures people can relate, but if you make it almost realistic but not fully real, then people can be uncomfortable. That may be happening with the Forest—do we need to make it more cartoony, so they're not bothered by what's not quite there…..it would be interesting to explore that. *(Project staff)*

Role of the Facilitator

The role of the facilitator varies for each My Dome experience, but each requires someone familiar with both the content and the intricacies of the immersive experience. The leader of the Temple of Horus needs to be someone who is very knowledgeable about Egyptian life, and can drive the game, while engaging the audience in an interactive presentation. Leaders for the Moon Base and Tikal need to be very familiar with the layout of the environment in which they are guiding students, even though students are the ones doing the exploring. The leaders also should be prepared with thought-provoking questions and challenges to prompt problem-solving in the groups, and the technical knowledge to drive the game itself.

Summary/Discussion

Success and Sustainability

Project staff described the achievement of their primary goals, focusing on the creation of four immersive experiences—Temple of Horus, Living Forest, Ghost of Tikal and (still under development) Moon Base and the various technical challenges inherent in their work.

> *The biggest goal was to see if you could do this, getting interactive pieces to work nicely, that has been the biggest success. The Forest is a beautiful rendering and you can use the controller in Egypt and Tikal getting Unity and everything to work was challenging technically, getting it to work smoothly. I think we did pretty good, we had 6 year-olds using the controller, they can use the technology, that removes technology as a barrier to learning, so they can interact with the immersion.* *(Project staff)*

> *I think we've done really well by making four [experiences] counting Monster Trucks [Moon Base]—that's too new [to evaluate] but Forest, Tikal and Temple all appear to work reasonably well, the audience gets something out of it and with [further] development they could be valuable tools. Looking at research, half of all projects fail and they have nothing to show for their work, and half of those that are done, nothing happens, they fail.* *(Project staff)*

Staff also emphasized the potential of dome experiences in schools/formal educational settings, as noted below, and how these products may be used going forward.

> *I think domes are on the cusp of getting more traction in schools. As more informal science centers are partnering with schools, they have more expertise to bring domes [to schools rather] than expecting schools to maintain it, could be on verge of exploding, it's on the verge. Our project showed you could do more in a dome than a passive movie.* *(Project staff)*

> *The project has significantly improved the virtual Egypt show with a mediated presenter. Public VR is selling Tikal and Forest and Houston is selling Tikal. Some publications and presentations that shared what we're doing with our community [have also been developed through My Dome].* *(Project staff)*

Several of the developers commented on the challenge of creating these immersive experiences with limited budgets and resources.

> *It's under par compared to a game company that spends millions of dollars but comparing it [Temple of Horus and Living Forest] to a small company's [work] it's on par. The budget was pretty small. The work done was valuable. I found it interesting and invaluable for the community…I think it has the potential to go where it needs to go, it's about budget and time, the hardest thing to get.* *(Project staff)*

> *The eternal lament, I wish we had somewhat better equipment, higher resolution, a better field of view in the dome, the image starts high up. That's minor…I would have liked to have been more involved in the pedagogy—I was contracted to provide the temple [Horus], and the forest, I edged in to the center of the project over time as the work progressed….* *(Project staff)*

Ongoing questions and next steps

My Dome staff identified a range of questions raised by their work within the project. Staff were interested in learning more about the best ways of engaging students in various settings, and in exploring solutions to various technical challenges, as noted in previous sections of this report. They also identified possible adjustments to the various My Dome experiences, such as Living Forest and the Moon Base.

> *How realistic/where do you draw the line? How do you make the technology accessible enough that more venues can create their own programs? It seems the technology would be pushed out there more quickly if people could make their own content. I think Lego has content to create their own movies…Unity is not quite modular.* *(Project staff)*

> *Teachers said, Could we add to this and add photos and our own content? This came from teachers and graduate students…can I build something and show it on the dome, how long will it be before that can happen, so the dome becomes like a VCR, accessible to anyone who wants to build content, that would open it up to a broader audience.* *(Project staff)*

> *For Forest and tools—we need to correlate them with real tools and [real] forests and show changes over time and show forests in different ecosystems, like a New Hampshire forest is really different than Western Pennsylvania……Once you set the kids loose and the presenter gives up control over the virtual world, what's the best way to share information?….how to embed information, do you get prizes for finding it [answers] as you go, there are all sorts of questions there…..* *(Project staff)*

> *I'd like to do a comparison study [with students] learning about the forest without Living Forest and with Living Forest, having a control group. I'd like to see kids [using] a curriculum with Forest on a flat screen or Tikal on a flat screen because you might get all the benefit you need [from flat screen] rather than a dome, you might get what you need. The danger is you might find the dome is no better and that undercuts our business. Interaction tends to be the primary factor…..my research was about this, what are the affordances of the dome that facilitate this?* *(Project staff)*

> *I'm completely happy with Egypt [Temple of Horus] and would show it as is for decades. I think Forest can improve significantly and I've taken over programming. Not sure what to do with Tikal and Moon Buggy [Base] is still at the early stages….* *(Project staff)*

My Dome staff also faced the challenge of making interactive experiences engaging and hands on. Students are often engaged by films, but need to be active and involved in immersive experiences.

> *It's interesting, you can put them [students] in the dome and watch a movie and they can be mesmerized but if you put in the interactive and they're not active [leads to problems]…..it was interesting to me that you could lose the kids so easily if there wasn't something specific, if there wasn't' something for them to do, that was eye opening.* *(Project staff)*

As noted previously, staff continue to refine the Living Forest and Tikal, and the Moon Base is still being tested. However, several of these products are currently being marketed, and dissemination should continue as the experiences are further developed/enhanced.

We're talking with schools and when we have teacher workshops for other projects, showing it to teachers, like when you visited, and we show it at events, there's an astronomy festival at UNH in October, we'll hand out flyers…also talking with libraries for summer programs. Now [co-PI] is advertising and running a lot of dome programs in Pittsburgh, she has an outreach program, and then the Discovery Dome network is advertising Tikal and will be advertising Forest, we're not ready yet…..but there's a gap because you need a knowledgeable educator for each of these.

(Project staff)

Conclusion

Our data show that My Dome staff have created four diverse experiences for the dome (and other) settings. Each experience presented different challenges to project staff, and each appears to be engaging for some, if not all, participants. A number of factors identified in this report, including group size, age/other demographics of the participants, the skills of the guide, time spent in the dome, and other contextual factors—such as viewers' interest in a particular topic—all appear to influence the dome experience. One of the experience developers, cited in this report, commented on the relative 'newness' or youth of the field of Virtual Reality and the use of domes for interactive experiences. Over the course of this grant, My Dome staff have added to the breadth of knowledge in this emerging field, and have identified new questions, which merit further study.

Appendices

Appendix A: PI Interview Protocol

Appendix B: Living Forest Survey (post)

Appendix A: PI Interview Protocol

What have you learned about creating effective immersive experiences through My Dome?
- Overall?
- Related to group size
- Age group
- Type of learner
- Informal vs formal settings
- Technical factors
- Other factors (degree of interactivity vs passive learning,
- The development process? What would you do differently ?

How do you see these experiences as connecting with formal education and teachers' needs/state standards?

Specifically what have you discovered about visitors' learning in the dome?
- What facilitates learning and engagement?
- What inhibits it?

What has gone well/in what areas have you been most successful?

What has been most difficult/challenging about the project?
- Probe: Where have you been less successful?

What limitations have you identified related to this type of dome experience?

What might you have done differently, based on what you've learned?

What will My Dome leave behind?
- Products
- Impact on students, teachers, etc
- Your understanding of teenagers/students in the dome

How, if at all, do you think these experiences will be used going forward?
- Probe: How will you market/distribute them?

In developing these experiences, has anything surprised you? [Please explain]

Have you seen any evidence that the dome experiences stimulate participants' interest in science and/or science-related careers?

Based on your experiences in My Dome, what questions do you have now?

Where will you go from here with these projects (continued work, new grant, etc)?

Appendix B: Living Forest Survey (Post)

Please answer the questions below – if you don't know an answer to a question, that is okay, but please write in "I don't know," and don't leave any blank. You do not have to put your names on the paper. Thank you!

1. What did you like the most about The Living Forest show?

2. Can you name three trees that grow in New England?
    1.
    2.
    3.

3. Please list 2 reasons why you think trees and forests are important. If you don't know, you can write, "I don't know."
    1.
    2.

4. Did anything in The Living Forest surprise you? What was it?

5. Which of the following things do you think happen as a forest gets older? (check all that you think are true)
    - ☐ Trees get taller
    - ☐ Different kinds of trees start to grow
    - ☐ Branches get longer and wider
    - ☐ More sunlight reaches the ground
    - ☐ Tree trunks get wider

6. Please circle which word best completes the following sentence:
    *As the forest gets older there is **more/less** (circle one) light on the ground under the trees.*

7. The difference between deciduous and conifer trees is (check all that you think are true):
    - ☐ They have different types of bark
    - ☐ They live in different parts of the world
    - ☐ One loses their leaves/needles every fall and the other keeps them

8. Is there anything you are wondering about trees or how forests grow and change? If so, write your questions below or on the back.