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Learning in an immersive digital theater

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Abstract

The Houston Museum of Natural Science, in collaboration with Rice University has an outreach program taking portable digital theaters to schools and community sites for over five years and has conducted research on student learning in this immersive environment. By using an external independent evaluator, the effectiveness of NASA-funded Education and Public Outreach (EPO) projects can be assessed. This paper documents interactive techniques and learning strategies in full-dome digital theaters. The presentation is divided into Evaluation Strategies and Results and Interactivity Strategies and Results. All learners from grades 3–12 showed statistically significant short-term increase in knowledge of basic Earth science concepts after a single 22-min show. Improvements were more significant on items that were taught using more than one modality of instruction: hearing, seeing, discussion, and immersion. Thus immersive theater can be an effective as well as engaging teaching method for Earth and Space science concepts, particularly those that are intrinsically three-dimensional and thus most effectively taught in an immersive environment. The portable system allows taking the educational experience to rural and tribal sites where the underserved students could not afford the time or expense to travel to museums.

Keywords: Earth; Planetarium; Immersive; Fulldome; Fisheye; Learning; Education; Outreach; Volcano; Canyon; Portable; Underserved

1. Background

The Houston Museum of Natural Science, in partnership with Rice University and with NASA funding, opened the first internet-downloading digital museum exhibit in 1994, and the products from that Digital Library Technology project, "Space Update", "Earth Update," and "Space Weather" have reached well over a million learners, with over 150,000 CD-ROMs distributed so far (Reiff and Sumners, 2004). In late 1998, that partnership created the first fully digital immersive fixed theater in the United States (and only the second in the world), under NASA Earth Science Information Partners (ESIP) support. Since then, the educational shows developed for that venue have been shown in many other fixed theaters, reaching another million learners. In 2003 we began a project to bring high-quality digital immersive shows to the schools using a portable system with an inflatable dome, funded by the NASA REASoN program in the office of Earth Science. The Immersive Earth project has worked with hardware manufacturers and software designers to create a system that is easily portable and popular with students.

1.1. Outreach to underserved populations

The tremendous advantage of a portable system is that the system can be taken to events to reach communities who are underrepresented in the sciences. Our project has focused on reaching Hispanic populations (through the school district and in special events such as the annual Brownsville NASA day); to women (through the annual Sally Ride Festival); and to Native Americans (through visits to Native American schools). The PI and the Co-PI of the project, both women, were encouraged in their child-

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hood to pursue science careers partially because of informal science experiences in planetariums, and are convinced of its effectiveness as a tool for inspiration. Fig. 1 shows the line of girls to enter the dome at the 2006 Sally Ride Festival, and demonstrates the eagerness of girls to experience science in this unique way. At the 2006 Brownsville Texas NASA day, over 60% of the 600 Hispanic students chose to learn about Earth science in the dome, keeping it filled to capacity. For the 2007 Brownsville NASA days, two Discovery Domes systems were provided so that all students could have the learning experience and more than 90% of students chose to visit the dome; in the 2008 session, that number was essentially 100%. Virtually all students interviewed said that the dome was their favorite session that day.

Over 120,000 Houston-area students have learned in the domes over the three years that they have been traveling, plus many more through our growing partner network. Schools are especially happy to have the dome come, because it is cost-effective instruction: "a field trip without the bus." Students do not have to bring permission slips, and the dome experience occurs only during their science classroom period, so they do no have to miss their other classes. Over 300 students can be accommodated in a school day, at a cost comparable to a third of them taking a bus to a museum. For rural students, as in the Brownsville or Native American tribal sites, a trip to the closest major museum would involve many hours of driving and would take too long and too much money. As an example of a typical school year schedule, an entire middle school (1100 children plus their teachers) received science instruction in the dome over the course of three days, and we received over 200 thank-you notes from the students (a few are shown in Fig. 2). Teachers in the Rice

Fig. 1. A line of middle-school girls waiting to enter the Discovery Dome at the Sally Ride Festival at Rice, October 28, 2006. Nearly 1000 students plus parents and teachers attended; more than half were able to visit the dome. For the 2007 Sally Ride Festival, over 1400 girls attended and again more than half received instruction and inspiration in the domes. Girls are an especial target for NASA education projects, since they are traditionally under-represented in science, technology, engineering, and math (STEM) professions.

University "Master of Science Teaching" program are allowed to check out a dome for their schools. Long-term rentals are also effective, with one school district reaching over 10,000 students in a 2-month period. Partners (National Research Council, 1995) in over 19 states and 12 foreign countries are now part of the Discovery Dome network, with more added weekly Sumners and Reiff, 2006. Some systems are owned by school districts; some by museums, and some by Challenger Centers or other outreach organizations. It is clear that evaluation of the scientific benefit of the experience is crucial for continued support to develop additional shows and to fund additional dome systems in targeted sites.

The Museum now has 12 shows that travel to schools. Each school chooses their own programs based on grade level and instructional needs. (Each show is classified as to grade level and national science objectives Sumners and Reiff, 2006.) Each class can see the same show, different shows, or several shows. Some shows feature specific NASA missions; others are more general topics. These shows have been developed by HMNS or the HMNS/Rice partnership:

Earth's Wild Ride (2–12); general Earth science topics; (NASA REASoN sponsor).
Force 5 (3–10); Earth weather and space weather (NASA ESIP and IMAGE mission sponsor).
Dinosaur Prophecy (5–12); climate change, plate tectonics (NASA REASoN sponsor).
ASTRO 101: The fundamentals of Astronomy.
Microcosm (5–12); human body (Rice Smalley Nanotechnology Institute sponsor).
Lucy's Cradle (5–12): human evolution, climate change (HMNS).
Fantasy Worlds (8–12): extremeophiles and astrobiology (UH sponsor).
Future Moon (2–12): history of the Moon; past and future lunar exploration (HMNS).
Amazing Astronomers of Antiquity (4–12): history of astronomy (HMNS).
Night of the Titanic (5–12): Ocean currents, icebergs, solar influences on climate (HMNS with REASoN and IPY support).
Saturn, the Ring World: Jupiter and Saturn (JPL Cassini support with HMNS fulldome graphics).
Secrets of the Dead Sea (5–12): geophysics and history (HMNS and NASA REASoN sponsor).
It's About Time (5–12): time cycles, space weather (HMNS, JSC with Rice content review).

To complete our educational goals, we also offer shows created by, and licensed from, other producers:

Heart of the Sun (5–12): Sun and space weather (license fees paid by the Cluster mission).
Secret of the Cardboard Rocket (K-5): tour of the solar system (license fees paid by the Texas Space Grant).

Fig. 2. A few of the thank-you notes we have gotten from students after the dome visits. Notes like these, and the "wow" looks on their faces, is more than enough reward for those of us who volunteer to teach with this unique system.

Mars (K-8): Mars missions and their results (license fees paid by HMNS).

2. Evaluation strategies and results

2.1. Evaluation plan

Independent evaluations of student learning in an immersive full-dome digital theater (Sumners, 2003; Sumners and Reiff, 2004) indicate that the immersive experiences created by full-dome video enhance learning – especially of difficult concepts requiring students to change reference frames. The research presented in this paper indicates that significant student content gains are also achieved with exposure to the portable digital dome theater (Weber, 2006; Sumners et al., 2006).

Two external evaluation studies were undertaken in 2006, and one in 2007. One involved a field trip to the Burke Baker Planetarium; the second and third were experiences in a portable Discovery Dome. One in 2006 was at a predominantly Native American school in New Mexico; the third was with predominantly Hispanic students in the Rio Grande Valley, Texas. All three studies used the same experience, a full-dome show called *Earth's Wild Ride*. This show features children born on the Moon learning about Earth as an alien planet during an evening watching an Earth transit (solar eclipse from Earth) with their grandfather. The child characters ask the questions that students in the audience would ask and the grandfather becomes the patient and enthusiastic teacher, parent, and tour guide. In this experience, students see the Earth in stark contrast to the Moon and compare the conditions on both worlds.

The evaluation instrument consisted of 17 multiple-choice items, displayed on one page in which students circled the correct responses. Each student took the instrument as a pretest within three days of the full-dome experience. The same instrument was administered as a posttest within a day of the experience. The answer sheets were handled, tabulated, and analyzed only by our external evaluator, Will Weber.

Three studies were conducted using this instrument:

1. Inner city student assessment in the Burke Baker Planetarium.
2. Rural student assessment in the portable Discovery Dome, tribal location.
3. Hispanic student assessment in the portable Discovery Dome, Brownsville.

Although the instrument was the same for all three studies, different evaluation protocols were employed with the different groups. Example multiple-choice items are available with other study material at http://earth.rice.edu/shows/EWR/.

2.2. Study A: Inner city population in burke baker planetarium

2.2.1. Description of study

The Houston Independent School District, the largest school district in Texas and the fifth largest in the nation, serves almost 200,000 students in Houston, Texas. It funds a planetarium experience for seventh graders in many of its schools. Jane Long Middle School was chosen as a representative school for this study. The pretest was given to all of the seventh graders on the day before their field trip to see *Earth's Wild Ride* in the Burke Baker Planetarium. Students were posttested using the same one-page instrument at school immediately after their planetarium experience. The Jane Long Middle School student population is 96% free or reduced lunch and primarily underserved minorities (African American: 7%, Asian: 6%, Hispanic: 83% and White: 4%).

2.2.2. Data analysis

Pre- and posttest results were paired for 221 students and the difference was evaluated using a t-test for paired samples and Cohen's d. Cohen's d is the difference between the means of the two populations divided by the pooled standard deviation for means. The criterion for statistical significance was set at the 95% confidence level ($p \leqslant 0.05$) and the criterion for educational meaningfulness was set at a standardized mean difference equivalent to one-half standard deviation ($d \geqslant 0.5$). To evaluate internal consistency with multiple choice questions, the Kuder–Richardson 20 reliability for the test is 0.72 – an appropriate value considering the low number of items (17). Difficulty factors for items range from 0.33 to 0.94 on the posttest and discrimination indices ranged from 0.3 to 0.7 for 13 of the 17 items. All items showed gains between pretest and posttests.

The seventh grade of Jane Long Middle School has two science teachers, labeled Teacher B and Teacher C in Table 1. Teacher B is a veteran science teacher while Teacher C is new to the field. The student performance indicates that the students of Teacher B had more prior knowledge than the students of Teacher C. However, both groups showed highly significant ($p < 0.001$) gains equivalent to approximately one standard deviation. The better prepared students of Teacher B showed greater learning gains than the students of Teacher C. Table 1 shows the results from this analysis.

Item analysis yielded additional information on the most effective teaching strategies for full-dome experiences. The 17 questions were classified by how students received the knowledge required to answer the question: by hearing, by seeing, through discussion between characters in the program, and/or by experiencing the concept through a full-dome simulation. Table 2 shows the effectiveness of the different modalities. Most questions involved more than one teaching modality. The percentage corrected score reflects the percentage of the questions answered incorrectly on the pretest that were answered correctly on the posttest.

Discussing and experiencing a concept are more effective in teaching students than just hearing or seeing the answer. It is also most effective to use more than one modality in teaching a concept – in this case the combination of hearing, seeing, and experiencing. In developing presentations for the full-dome, these results encourage the use of interactive narration that supports illustrations and immersive experiences. Perhaps the most surprising result is that student learning improved when characters discussed the content with each other. The power of discussion in teaching has led the authors to develop the use of discussion points within a show in the portable dome where the action can be stopped for discussion purposes. This interactivity will be discussed later in this paper.

Table 2
Effectiveness of different learning modalities

Learning modality	Number of items	Percentage corrected on the posttest (%)
Hearing	11	40
Seeing	13	39
Discussing	3	49
Experiencing	6	45
Items using one modality	5	36
Items using 2–3 modalities	12	40
Items using 3 modalities	4	59

2.3. Study B: Navajo reservation in discovery dome portable theater

2.3.1. Description of study

As part of its Astronomy Road Show, the Houston Museum of Natural Science sent its portable Discovery Dome to the elementary, middle, and high schools of Tohatchi, New Mexico (population 1037). Tohatchi (located in northern New Mexico near the Arizona border) is 92% Native American, 6% White, and 4% Hispanic with 2% reporting two or more races.

Students in grades 3–12 were pretested and posttested before and after watching *Earth's Wild Ride* in the portable Discovery Dome using the 17 item multiple-choice instrument. The tests were administered within one day of the experience. The tests for grades 6 and 10 were not returned, but all of the tests for the other grades were scored and analyzed. The results are presented by grade level in Table 3.

2.3.2. Data analysis

Highly significant gain scores were posted for grades 3, 4, 5, 7, and 8. In high school, the significance drops because the students have more prior knowledge, making the testing instrument less sensitive to content gains. Also, the sample size of students drops significantly in the higher grades – giving less significance to the results. At all grade levels, gain scores range from over half of a standard deviation to over a standard deviation.

The most unexpected result of this study is the age range of educational viability for the *Earth's Wild Ride* program. Normally educational products are tightly tied to specific grades and ages. This product is successful in grades 3–12. The authors postulate that the immersive quality and high activity level of the full-dome experience make it appropriate for many different student populations. The

Table 1
Results obtained from t-tests for paired samples for Jane Long Middle School students

Group	N	Pretest		Posttest		t	p	d
		Mean	SD	Mean	SD			
Teacher B	127	11.03	2.49	13.51	2.41	13.01	<0.001	+1.00
Teacher C	94	8.77	2.87	11.50	3.16	9.05	<0.001	+0.95
Total	221	10.07	2.88	12.66	2.92	15.34	<0.001	+0.90

Table 3
Pre- and posttest performance

Grade	Number	Mean score		Gain	SD	t-Value	p-Value
		Pretest	Posttest				
3	32	6.53	9.56	3.03	3.81	4.50	<0.001
4	36	7.33	10.39	3.06	4.04	4.54	<0.001
5	31	9.32	12.39	3.06	2.36	6.93	<0.001
7	34	8.97	12.62	3.65	2.47	8.60	<0.001
8	20	7.50	12.65	5.15	4.33	5.32	<0.001
9	21	10.90	14.09	3.19	3.53	4.14	0.001
11	10	10.60	14.40	3.80	2.62	4.59	0.001
12	17	11.82	14.12	2.29	4.09	2.31	0.034
All	201	8.72	12.07	3.33	3.49	13.60	<0.001

Table 4
Results obtained from *t*-tests for paired samples by class and for total group

Group	N	Pretest		Posttest		t	p	d
		Mean	SD	Mean	SD			
A	15	9.73	3.11	12.07	2.79	4.12	0.001	+0.79
B	20	8.55	3.03	11.30	2.76	4.24	<0.001	+0.95
C	19	10.21	3.17	13.79	2.44	4.47	<0.001	+1.27
Total	54	9.46	3.13	12.39	2.83	7.30	<0.001	+0.98

fact that it was developed for general public audiences also contributes to its wide acceptance by different audiences. Very different live interactions and accompanying curriculum support materials can also customize the experience for different ages.

2.4. Study C: Hispanic students in discovery dome portable theater

2.4.1. Description of study

In a third study similar to the second, three classes of predominantly Hispanic fifth grade students from the Rio Grande Valley took a pretest, viewed the show, and immediately took a posttest. The test site was the campus of the University of Texas at Brownsville. Again the test instrument was the same. We had planned to offer for these students, many of whom came from ESL programs, a Spanish version of the test instrument and a Spanish version of the show. However, the teachers related that by that grade level, all science instruction was attempted in English. More surprisingly, the teachers said that, despite speaking Spanish at home, many students could not in fact read Spanish. We then asked the assembled students if anyone would prefer to watch the show in Spanish and not a single hand was raised. So the show and the tests were conducted in English.

2.4.2. Data analysis

Table 4 and Fig. 3 present the results obtained when *t*-tests for paired samples that were used to determine whether the differences between pretest student achievement and posttest student achievement were statistically significant and Cohen's *d* (Cohen, 1988) was calculated to determine whether those pretest–posttest differences were educationally meaningful. As earlier, the criterion for statistical significance was set at the 95% confidence level ($p \leqslant 0.05$) and the criterion for educational meaningfulness was set at a standardized mean difference equivalent to one-half standard deviation ($d \geqslant 0.5$).

As shown in Table 4, when *t*-tests for paired samples were used to analyze the pretest and posttest achievement of the students by class and for the total group, all four sets of results indicated that posttest student achievement was statistically significantly greater than pretest student achievement. As in the previous study, there were differences between classes, but each class showed a near one

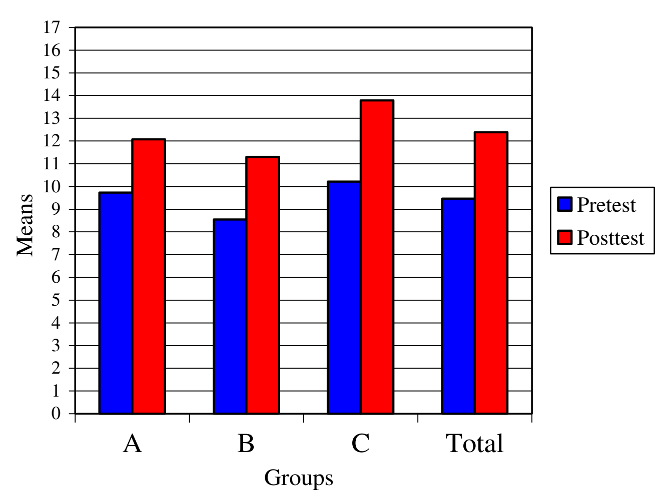

Fig. 3. Pretest and posttest Student achievement means by class and for total group (Brownsville students).

sigma gain. In addition, when Cohen's *d* statistic was calculated for each comparison, the pretest–posttest differences were found to be educationally meaningful.

For each of these studies the posttest was administered within a day of the dome experience. Further study is underway to measure long term effectiveness. Additional research specifically addressing the efficacy of the immersive dome in comparison with other learning methods is also underway.

Thus we can again confirm that statistically significant learning occurs even within the space of a single 22-min show.

3. Interactivity strategies and results

The portable theater offers unique opportunities for interactivity, not available in a large planetarium theater with a linear video presentation. The full-dome show, *Earth's Wild Ride*, was chosen for this research effort for several reasons:

(a) *Relevance to national and local education standards:* Since it spans both Earth and space science, this program meets at least 15 of the proficiencies required in Texas for the fifth grade standardized science test (Texas Education Agency, 2006).
(b) *Appropriateness of segments for group discussion:* Earth's Wild Ride divides into chapters – Moon base, solar eclipse, ice ages, volcanoes, impacts with dinosaurs, and canyons produced by clouds and rain. Each of these sections presents and illustrates different concepts where students can identify cause and effect and can compare the Earth and Moon.
(c) *Availability of specimens that could be examined by students:* The Houston Museum of Natural Science maintains teaching collections of specimens that relate directly to the program.

The Museum has employed two types of interactivity: pausing the show for discussion and pausing the show to distribute manipulatives or specimens while students are in the dome (Sumners, 2006). The pause function can be used with any audience. When the discussion between the grandfather and grandchildren finishes, the operator can stop the show and ask students the same question that the child characters asked or discuss why the child character asked a particular question. Table 5 lists the different manipulatives that can be used with the Earth's Wild Ride program. Other full-dome shows would lend themselves to other manipulatives.

Table 5
Manipulatives for interactive experiences, Earth's Wild Ride program

Show content	Manipulative
Mammoth	Mammoth tooth
Tyrannosaurus rex	T-rex tooth cast
Volcano	Samples of lava and pumice
Meteor Impact	Stony and iron meteorites, tektites
Canyon w/rain	Sedimentary rock with layering

In addition to the specimens related directly to the show and listed in Table 5, we also distribute rocks that students must classify as: (1) must be from Earth or (2) could be found on the Moon. Rocks with imbedded fossils and petrified wood are certain signs of an Earth origin. Sedimentary rocks are also only found on Earth. Igneous rocks such as basalts and breccias could be found on the Earth or Moon. From the content in *Earth's Wild Ride*, students are able to make these comparisons between the two worlds.

4. Conclusions

In summary, the full-dome video format, especially as it is used in the portable digital theater, has greatly expanded the content we can present for schools and for the general public. Evaluations of concept acquisition indicate that the digital dome theater can be successful in teaching non-astronomy concepts and can expand its role as a tool for learning at all grade levels for other fields of study, including Earth science and space weather. Our results show that subjects taught with more than one modality (hearing, seeing, hearing a discussion of the subject by the characters on the show, and experiencing using fulldome animations) are more effectively learned than using one modality alone, and that discussion and experience are more effective than just hearing or seeing. Our next study will be research on the role of immersion in learning, compared with watching a video or reading a story covering the same content as well as longer term retention of the material. Our next planetarium show, which opened spring 2008, is "Night of the Titanic", which teaches International Polar Year topics (icebergs, ocean currents, sun-climate connections) in the context of one of the most fascinating disasters of the 20th century.

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