The Art of Nurturing Citizen Scientists through Mixed Reality

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Abstract

Modern society requires the public to have an increased knowledge of science beyond the basics, with average people needing to understand concepts in science, technology, engineering and mathematics that rapidly evolve throughout their lifetimes. Our future depends upon closing the gaps between citizen and scientist to create a "Citizen Scientist." Mixed Reality innovations provide the magic to spark a lifetime of learning for community learning centers by continuously providing new content and reinventing the free-choice learning experience that helps citizens make informed choices in an increasingly complex world. This paper explores a Mixed Reality experiential learning landscape that expands our ability to provide dynamic content structures for venues to engage the user's physical environment and interactive imagination by incorporating the conventions of story, play and game employed in competing leisure time activities. This is intended to reverse the standard decline of attendance by teenagers and young adults.

1. Introduction

"Any sufficiently advanced technology is indistinguishable from magic."

--Arthur C. Clarke

Where the scientist brings in to the world new capabilities through inventions, it is the artist who provides new possibilities through innovative content. The function of Mixed Reality to melt the boundaries between real and virtual worlds is transformed to the purpose of Mixed Reality to create memorable experiences that last a lifetime. This is where technology must become transparent. Here, technological novelty matures into expressive ***media***. This is where the criteria of success are better measured in human impact rather than through technological capacity or economic performance.

With the experimental project, Sea Creatures Journey, Mixed Reality takes the form of an Experiential Learning Landscape that brings to life a static exhibit of fossils. The challenge is to enhance an existing exhibit's entertainment and economical value without diluting the educational impact, while simultaneously increasing a user's desire for longer and repeat engagement. The goal is to address the challenge of the 16,000 informal education venues in the United States to attract attendance among teenagers. At the age where lifelong habits and careers are formed, science centers are losing the interests of young adults. This impacts not only the scientific community, but society at large.

1.1. Informal Education: Free-choice Learning

With the impact of science and technology on society, the public needs to be informed and cognizant of the nuances and consequences of man's impact on the future world. Viewed as life skills, science, technology, engineering and mathematics need to be presented in compelling and meaningful ways that impact our curiosity from a young age and keep our fascination and desire for learning for a life-time.

In recent decades, this has been achieved by a proliferation of informal science education venues. These have been sparked by such classic examples as Washington DC's Smithsonian Institution, Brooklyn's Children's museum and San Francisco's Exploratorium. However, these venues frequently present only the basic scientific concepts. Science museums and centers are looking for vehicles to keep up with the advancement of science. New outlets such as the Internet, cable television and magazines have brought a fresh flow of science content that has forced the thousands of community learning centers to rethink and reinvent their core models of experiential learning to keep up. This reinvention is critical to their attracting and effectively serving a diverse population, on an on-going basis.

To meet the needs of these centers, new paradigms must successfully compete with the explosion of the other leisure time industries of video games and location-based entertainment that audiences crave in their time off from work and school. As a tool for lifetime, self-motivated learning, Mixed Reality must provide the ability to construct learning experiences with stories, games and free-play that increase the entertainment value without compromising the core learning objectives. The key is that MR can provide an interactive environment in which participants apply their creative imagination. Figure 1 depicts such an experience, Sea Creatures Journey, which we will discuss in section 3.

Figure 1. Mixing realities–Sea Creatures Journey

1.2. Magic: Painting with the Imagination

"Imagination is more important than knowledge."
--Albert Einstein

Learning goes beyond memorizing facts and figures. As William Butler Yeats suggests, "education is not filling a bucket, but lighting a fire." We need to spark the imagination before we can teach the mind. This is where entertainment becomes a medium of impact. However, the tradition of passive entertainment and educational instruction can be counterproductive as in many forms of "edutainment" that incorporate both, yet do neither. The next generation Mixed Reality must provide creative leaps in its form and structure of content that goes beyond the passive and reactive media of the last century, allowing free-choice learning to transform from passive viewing that is ***consumed*** to interactive objectives that are ***achieved*** with experiential media.

1.3. Real world application

"Entertainment can be passive, education can't; It is inherently interactive."
--J.C. Hertz, Author of Joy Stick Nation

In a series of experiential media research projects, the University of Central Florida's Media Convergence Lab has worked with Orlando's community education centers and experiential entertainment venues to help understand the diverse and complex challenges that face experiential learning venues. It has resulted in providing new models that can leverage the latest research in science, technology, media arts, operations and economics, as well as leverage the convergence of media technology and artistic conventions. These projects are designed to find solutions that can scale to international application. By partnering with public venues we can anticipate institutional limitations and minimize the obstacles of adoption. This is to create not only the "push" of technological innovation from research, but to also provide the "pull" from industry. Our media innovation infrastructure [7] makes it easier for venues to embrace radical advances, adopting new learning techniques and technology as fast as society is adopting the new science and technology. We develop solutions so they are not only technologically robust and economically viable, but they also validate educational purposes for the community that underwrites their operations through endowments and subsidies.

1.4. Innovator's dilemma

With a technological-savvy public, the traditional technology-challenged centers do not have the expertise or funds to keep up with rapid advances in display technology and content development. One problem is that every technology the center may adopt is quickly outperformed by home entertainment technology inspired by Hollywood and Silicon Valley. Mixed Reality concepts are proving to be an ideal innovation that is not only highly effective in transforming scientific research into compelling educational content, but provides an effective long-term solution, economically and operationally. Finding solutions involves more than adding new whiz-bang, sensory gadgets whose novelty is soon outdated. Through a multi-year process of experimentation, prototyping and evaluation, we can understand how Mixed Reality can provide a systemic evolution of new standards and practices for experiential, life-long, free-choice learning. New models are presented within operational constraints, which help learning centers to more easily create a better informed society, supporting their goal to be effective stewards of the future.

1.5. Creating the citizen scientist

"*The task of the future is to build knowledge and understanding among and between citizens and scientists, so that the distinction between the two groups vanishes –*

so that both become citizen scientists, potentially able to solve our problems together."

- Ursula Franklin, Royal Society of Canada, 1990

Since there has never been a time in society where so many average citizens needed to understand so much science in order to accomplish their basic civic duty of making informed choices, our goal is to invent the process and mechanism to create the future Citizen Scientist. With the impact of advancing science on modern society influencing economic, religious and lifestyle issues, an uninformed public has the potential to be as damaging to the future as the science and technology itself. For scientists and citizens to come together and speak the same language, individuals of all ages and backgrounds need to become more scientifically literate without having to return to compulsory education.

Communities are seeking alternative life-long free-choice learning opportunities that go beyond basic scientific concepts and tap into the actual science being explored in research. These options need to provide a richness, diversity and flow of content equal to the video game industry, while delivering the breadth and depth of the science affecting society. Mixed Reality allows us to apply one of the core tools of the modern scientist, Scientific Visualization, and transition it to a form that supports real-time interactive learning that can be integrated within the traditional science center and museum. This is the environment we call a Mixed Reality Experiential Learning Landscape that can help melt the distinction between the scientist and the citizen in making informed choices for the future.

The following concept of a Mixed Reality Experiential Learning Landscape is the product of case studies (described in section 3) that provide empirical evidence to help us understand how to create the next generation of free-choice science learning, bringing new knowledge to communities in a compelling and economically feasible way. These applications inform our research to insure more successful adoption of Mixed Reality in other challenging environments and applications, such as entertainment, marketing, retail, tourism, cultural heritage and military training.

2. MR ELL Model

The Mixed Reality Experiential Learning Landscape model described here is leading up to the development of a distributed simulation project called POW!, The Power of Water. Simulations of the science of hydrology are created from ***real*** scientific data provided by federal and local sources (such as NOAA and regional water authorities) and applied to ***relevant*** climatic regions from diverse communities. Using open, interactive and immersive mixed reality displays, POW! activities ***engage*** group interaction to make the experience ***relational*** within ***compelling*** game-like scenarios, scaling to ***adapt*** to each unique venue. With video capture and telepresence the experiences ***transcend*** the physical exhibit to tap into remote research locations, and to the home and classroom with ***persistent*** virtual environments.

Falk & Dierking's continuing work on the Contextual Model of Learning [1] with its three overlapping contexts – Personal, Sociocultural and Physical – and the personal meaning that visitors need to see in the social environment of science centers is setting the stage for the relevancy issues that will be addressed in POW! .

With the recent bombardment of hurricanes that hit Florida, people cursed the destruction, but few realized how that natural phenomenon is a part of a larger cycle of the earth system of hydrology that contributes to Florida's unique habitat, the Everglades, made up of interconnected underground rivers in the form of an Aquifer that recycles prehistoric water from ancient seas in which reptiles once swam. With dynamic mixed reality simulations augmenting ecosystem exhibits, outdoor vistas and remote scientific sites, visitors are able to interact and manipulate "what if" scenarios from the microbe to the global and from the prehistoric to the present. With a better understanding of the larger life cycle through simulations, citizens start to understand what impact their everyday decisions and activities can have at a global scale over time.

With the same scientific virtualization content distributed to science centers and museums having diverse climates, the dynamics of hydrology can be programmed to adapt to each community's venue configuration and weather conditions.

2.1. Implementation requirements

Elaborate environments, both natural and man-made, will be augmented with scientific virtualizations that exist in venues of collaborating partners from aquariums, botanical gardens, recreations of swamp ecosystems, outdoor vistas of desert mountains and reconstructed prehistoric habitats.

With distributed, scalable, interoperable, customizable simulations in the form of simulated learning landscapes, individual community institutions will not be constrained by their own limited resources or geographical boundaries. The development of Mixed Reality Experiential Learning Landscapes will make it cheaper to create and more profitable to distribute experiences that help visitors become more informed and concerned about their community. This can be credited to the ability of Mixed Reality to leverage the existing physical environment and tap into each visitor's limitless imagination.

2.2. Scientific foundation

The model of the Mixed Reality (MR) Experiential Learning Landscape (ELL) is to provide a continuous pipeline for real Scientific Virtualization models from sources such as NOAA, NSF, and USGS to transition seamlessly into existing community learning centers, providing the maximum impact with the minimum burden to the institution. This process incorporates the latest advances in experiential entertainment and learning. The next generation of richly layered, multi-sensory, immersive Mixed Reality provides us the ability to embed this dynamic medium into a traditionally unchanging static environment. The objective is to increase the depth and breadth of learning opportunities for community centers while increasing the quality of content experience that can successfully compete with the local arcade or theme park. Simultaneously, these experiences need to adapt to attract and appeal to a broader spectrum of demographics to serve all of society.

2.3. Mixed Reality ELL framework

The internet, cable television, science and technology television shows, websites and magazines all provide diverse and up-to-date content that starts to address the need to inform the public on an international scale. The application of mere audiovisual media to exhibits with interactive levels equal to the internet has proven to be less effective than expected due to the fact that audiences can get the same experiences at home. Community learning centers such as science museums and centers are both immersive and experiential and they need to transform those ideas and images into dynamic, interactive and immersive experiences more akin to experiential entertainment venues like theme parks than to passive media outlets such as movie theaters.

The framework below (figure 2) outlines how Mixed Reality becomes the enabling technology to integrate Scientific Virtualization into existing community learning centers, providing a pipeline of future content.

Scientific virtualization

The dynamic capability of virtual reality, real-time, interactive 3D simulated models that researchers use to experiment with a simulated world is called ***Scientific Virtualization.*** This allows scientists to form detailed recreations and salient abstractions that play out "what if" scenarios for compelling insights. This technology is the foundation of the MR ELL and allows us to directly transfer real science to experiential content.

Entertainment content structure

The explosive growth of virtual technologies within video games, animation and special effects movies is based on the same technology that is needed for Scientific Virtualization. By applying the conventions of the three key forms of entertainment – story, game and free-play – real science converges with instructional strategy.

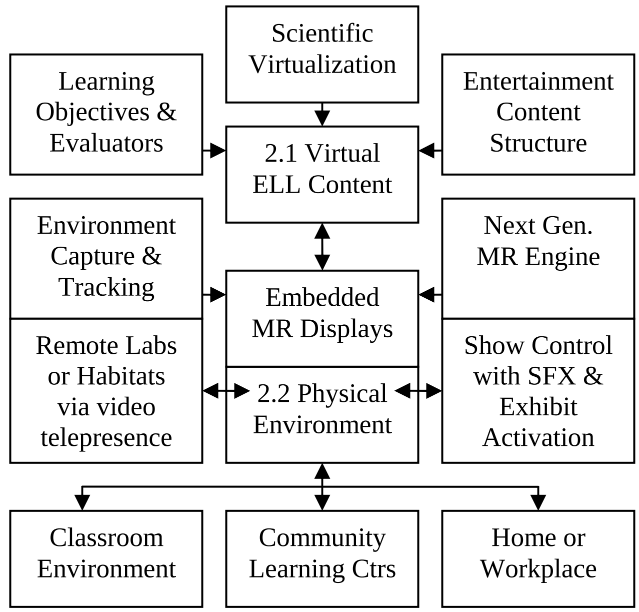

Figure 2. MR Experiential Learning Landscape

Free-Choice learning objectives & evaluations

Museums originated as places to display the artifacts of art, science and cultural heritage. They augmented traditional education with tangible evidence experienced in close proximity. This was called Informal Education due to the fact it was meant to spark curiosity and interest in formal compulsory education. Science Centers evolved to deliver informal learning through dioramas, interactive displays and entertaining multi-media that created a social, as well as compelling experience.

The requirement of future community learning centers is to provide an experience that increases public understanding of modern science. To do so, a center needs to combine ***real*** science with context ***relevant*** to its community and become a ***relational*** interaction with peers, parents, scientists and policy makers. This environment needs to be fed a continuous flow of dynamic content that addresses the breadth and depth of science, as well as adapts to the diversity of its audience and venue requirements.

2.4. MR ELL environment

The software will be distributed to diverse exhibit venues and, as such, needs to adapt to its various environments using each one's individual physical assets.

Separate from the MR content, the Environment Capture and Tracking will composite the virtual content with the physical 3D space. Visitors will be able to have multiple viewpoints through various Embedded MR Displays. The Next Generation MR Engine will drive the scenarios with the use of a story engine that integrates a graphics engine, audio engine and special effects engine, the latter of which operates the show control and manipulates the physical environment.

With the cost, time and expertise needed to change out exhibits, these learning experiences can take years to be modernized. As a consequence, tired exhibits reduce membership renewals and attendance. Where the exchange of traveling exhibits can bring new options, most often they present the same information in every community and cannot adapt to include more custom material with specific relevance to each community. An example of this relevance might be to present how the science of hydrology affects a specific community's understanding of water conservation in a desert versus a swamp or temperate rainforest.

Video Telepresence will allow for the learning experience to extend to participating laboratories and habitat environments.

2.5. Distribution across environments

With scalability, reusability and adaptability, the MR ELL can adapt to other community learning centers, classroom environments, homes and workplaces.

The community learning centers must now constantly validate their existence to local community leaders, taxpayers, visiting schools, and nationally recognized standards of educational excellence such as those established by the National Science Foundation.

Community-based free-choice science learning venues must provide unique, entertaining and compelling experiences that can keep up with the latest scientific advances, as well as provide unique implications to individual communities within their economical and operational constraints. Can the average science center compete for audiences and validate its costs in federal and local funding, as well as endowments? That is the challenge facing Mixed Reality as a viable tool for informal science education. Addressing this requires not only the validation of the technological invention, but the creative and economic innovation that requires research to go beyond its confines of the laboratory.

3. Case Studies: Empirical Foundation

The conclusions and observations of this paper have been formed from critical case studies for education, training and entertainment that have each created diverse prototypes developed in partnership with local and international partners. They draw upon the authors' integrated experiences including 20 years of developing science centers, 25 years of creating experiential entertainment, and 40 years of research in the science of computer simulation and graphics. Each evolution was intended to better understand and articulate the diverse and complex challenges that arise in successful innovation of free-choice learning and not just to technically validate a particular invention. Our goal was not to make incremental improvements to technology, but to make creative leaps within the application – learning what will better impact and inform future generations. The end goal was to create a model that could bring a higher flow of compelling scientific knowledge to those who most need it, kids of all ages and backgrounds.

Each case was considered a prototype that resulted in field installation or testing within an actual public venue to obtain the most relevant data. Each experiment adapted different levels of physical and virtual augmentation to better understand the relevance of the entire spectrum of Mixed Reality. Journey with Sea Creatures was our central case study whose formative evaluation defined the model of the MR Experiential Learning Landscape detailed in section 2. It validated the feasibility of a *Delivery Model* that an average sized science center could afford to adopt, which included an unencumbering, multi-sensory Mixed Reality display that provided extensive enhancement to an existing core exhibit. Currently, the future MR ELL model is in the preliminary concept stage being developed by a nationwide collaboration of institutions ranging from leading museums to mid-sized community learning institutions.

3.1. Sea Creatures Journey case study

The CEO of the Orlando Science Center challenged our team to transform a traditional core exhibit that was valuable to the mission of the museum, but was not drawing new visitors or repeat visits from the public and members. We needed to not only expand the learning experience by augmenting the environment with Mixed Reality, but also provide a conduit for a continuous flow of content that was as satisfying as the local entertainment attractions such as Universal Studios and Walt Disney World, and their commercial rival Wonder Works. It had to provide entertainment value, without undermining its educational value.

The Journey with Sea Creatures case study transformed a core paleontology exhibit called "Dino Digs: Mysteries Unearthed" by compositing static fossils into a Mixed Reality Experiential Learning Landscape (figure 3) [3]. Two previous case studies informed its design. The MeasureMe exhibit, also at the Orlando Science Center, served as a preliminary evaluation in that it provided a highly interactive exhibit with the augmentation of computer generated statistical simulations. It informed the requirements of the free-choice learning experience. The second case study, the invention of an experiential movie trailer created for MGM for marketing within retailtainment venues such as shopping malls, informed the technical implementation of providing a big experience with minimal infrastructure. The result was to bring prehistoric marine reptiles to life within a Mixed Reality video game that encompassed the entire exhibit space [3], [7].

Figure 3. Composite of physical and real assets

3.2. Preliminary content case study

The preliminary case study of MeasureMe helped to define the core free-choice learning requirements for Sea Creatures and provided insight on transferring the content across instructional environments. The experience augmented an exhibit with computers that was to excite kids about what could be a very dull subject—statistics. The final solution needed to engage a core target (10-16 year olds) as well as entice more participation from formal classroom application and home schooling environments, which are a core business of any science center. The content went beyond a minimally reactive computer display on the periphery to being a dynamic display whose simulation was integral to the interactivity and thru-line of the experience [2]. This provided a dynamic analysis of persistent data sampling collected over the entire life of the exhibit (five years at this point). This data content could be transferred into the classroom and home for continued formal and independent learning.

The MeasureMe experience used a computer network of interactive stations that captured measurements of varying aspects of your body and performance (reach, balance, jumping height, weight, reflex, etc.). At the beginning of the exhibit, visitors obtain a ruler with a bar code. At each station, computers read your assigned number from your ruler and collected another piece of demographic data (anonymously) with each measurement (figure 4). Lying about your real data is acceptable and part of the data analysis process (we had a few 150 lbs, 3-year old toddlers recorded). Your individual data are compared with the growing data base. Central to the exhibit is a set of analysis stations where statistics help students learn more about what interests them most, themselves. Without connecting to individual identities, a visiting class is able to mark a subset of data for further analysis in the classroom. Data can also be collected at home and entered manually by members for home schooling.

Figure 4: Grip strength station

Evaluation

Early focus groups of students and teachers from the target demographics tested subject matter activities for the analysis stations. Where statistics were a deadly turn off to most students and adults, relating the activities to relevant issues captured their curiosity and imagination. Visitors felt a sense of ownership of the data, because it was about them. Simple competition (who among friends can hang the longest) and comparison (how do I compare with all visitors who ever came to this exhibit) added to the excitement and connection.

The primary evaluation was focused on establishing how learning content needed to be adapted in order to be relevant to different environments (classroom, exhibit, and home). We took the core analysis exercises within the museum experience and made them available for field-dependent instruction within the classroom and also available in a computer lab environment for field-independent instruction. The experiment evaluated the same 50-minute learning experience in three environments to determine the effects of cognitive styles and learning environments on the teaching of statistics with computers. Pre-tests and post-tests were taken to establish cognitive styles, competency and preferences.

The experimental design included 174 students from two different public schools; subgroups of 50 students were tested individually within each environment. The hypothesis of the evaluation anticipated significant differences with the results based on the students' cognitive styles (field-dependent and field-independent). However, the differences between each cognitive style were statistically insignificant.

The surprising result came from the fact that each environment had significant effects on different aspects of learning. The science center resulted in having a significantly higher impact in improving ***attitudes*** towards statistics and computers than did the other two venues. The classroom resulted in significantly higher ***performance*** levels than the other two environments. The real surprise revealed that the independent learning within the computer lab provided significantly higher ***satisfaction*** in learning (figure 5).

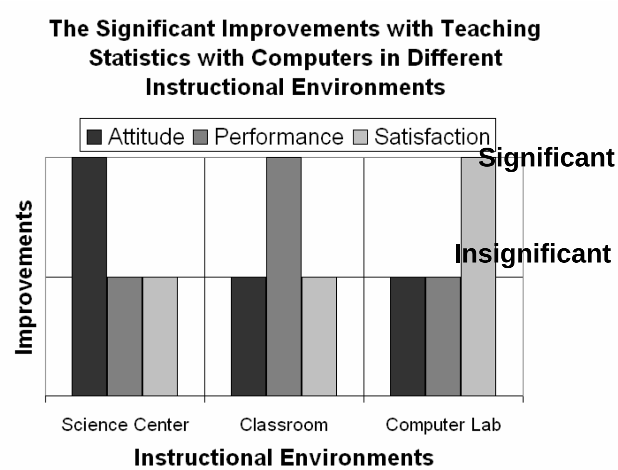

Figure 5: Effects of instructional environment

This emphasized the impact of the environment within the total learning process. The shortfall of many media forms is that they do not engage the user's environment and cannot change from one context to another. In contrast, Mixed Reality has the ability to leverage the advantages of each unique environment.

Conclusion

The resulting insight of MeasureMe is that Mixed Reality in experiential learning venues must create experiences that are real, relevant and personal to the student and mentor across instructional environments. These resulted in the key design parameters for the next application of the Mixed Reality Experiential Learning Landscape:

- Free-choice learning experiences need to be ***real***, engaging not only the user physically, but also engaging a responsive environment that immerses the subject in a multi-sensory encounter of perception, interactivity and awareness.
- Free-choice learning experiences need to be ***relevant*** to the user, focusing on each person's data, observations, preferences, and age-appropriate interactivity.
- Free-choice learning experiences need to be ***relational*** to promote human-to-human interaction with the user's mentors, peers and community to have the emotional and memorable imprint for long-term effect.
- Free-choice learning needs to ***transcend*** learning environments and ***adapt*** to each one's strengths.
- MR learning experiences need to be ***compelling and engaging*** by integrating interactivity and entertainment directly to the learning objective and not peripheral issues. If this is not so, visitors will skip over learning to capture the next physically engaging or entertaining activity.
- MR learning experiences need to be ***persistent*** in order to leverage all three instructional environments and have augmented activities that extend the experience beyond any one place.

3.3. Preliminary Infrastructure Case Study

The preliminary case study of "Time Portal," an experiential movie trailer for MGM shown at SIGGRAPH 2003 [6], provided a successful prototype for the implementation of Sea Creatures. It entailed the convergence of entertainment content formats in order to market MGM brand entertainment. It was designed to look like a film, play like a game and have a multi-sensory immersion like a theme park. The model provides multiple levels of interactivity to achieve a high capacity and throughput of guests (figure 6).

The relatively small footprint of the Mixed Reality Time Portal (figure 7) was placed within the existing fossil exhibit (figure 8). The scenic casing and environmental audio and lighting effects created an intriguing and stimulating attraction that was hard to resist within the static exhibit space. As visitors walked around the Mixed Reality Portal, they could see the actual exhibit via live-feed video projected on a dome screen. Video captured docents were able to walk around the exhibit, showcasing particular educational threads and drawing unique visual aids from the exhibit itself with comparisons of artifacts displayed around the environment.

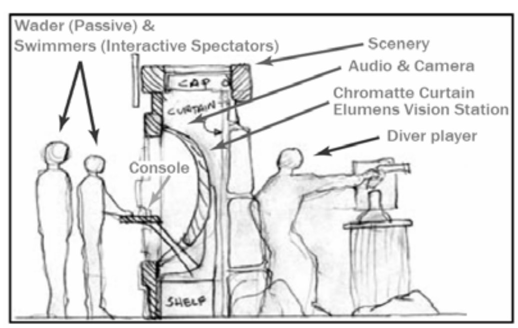

Figure 6. Different modes for different interactors

Community science centers cannot afford the cost, maintenance or operational staff needed for the adoption of the extremely successful video see-thru, stereoscopic mixed reality head mounted display (HMD) that also requires expensive tracking systems [8]. We adapted our invention of the Mixed Reality Portal to a non-encumbered form that accommodated group interaction. Without HMDs, we needed to convincingly establish a sense of presence beyond the projection screen for the technology to seem transparent. The use of our mixed reality audio engine and displays allowed for the real-time capture, mixing and display of hybrid audio through the portal and interaction between virtual creatures and live guests [4]. For permanent displays, the physical exhibit environment will be wired and activated to respond to virtual cues with sound, show action equipment and artifacts. The savings on capital expense allow extensive development of the experience itself.

Figure 7. Time Portal at SIGGRAPH 2003

3.4. The resultant Sea Creatures experience

The combined lessons learned from the content and infrastructure case studies formed the design of the Sea Creatures Mixed Reality Experiential Learning Landscape.

Figure 8. Reuse of portal in Sea Creatures

Through Mixed Reality, the entire exhibit hall at the Orlando Science Center was filled with virtual sea water and we were transported back to prehistoric (Cretaceous) times. Creatures came alive from within the exhibit and swam around (mcl.ucf.edu/archives_videos.htm). A virtual paleontologist guided us via a video telepresence view from his lab. Below the portal were controls and virtual instrumentations showing us how to navigate the environment to collect artifacts throughout the underwater exhibit. Since our portal was stationary, we were given a virtual, remotely automated underwater vehicle that we could control to see a dynamic virtual perspective from the vehicle's point of view.

- To make it ***real***, the system masked the technology with a thematic stone outcropping. Multi-sensory displays and tools were integrated with audio and visual rendering algorithms that blended the light, color palette and ambient acoustics with computer generated models.
- To make it ***relevant*** with our target, teenagers, the experience mimicked a video game design that used multiple control inputs and a Heads-Up Display readout of current real-time data. Establishing the relevance to the community, the exhibit hall was flooded with prehistoric sea water to emphasize that Florida was once under the sea.
- We achieved the ***relational*** interactivity with peers and mentors through the use of a large, open projection display with live video feed. With pre-tests of the Mixed Reality portal, large groups could interact together. The use of live feed video prompted kids to engage with their peers and mentors within the Mixed Reality sea.
- The use of video see-thru Mixed Reality was critical to ***transcend*** the museum environment with live-feed or capture equipment. The virtual content was able to easily ***adapt*** to different instructional environments.
- Given the theme of dinosaurs, visitors automatically expect a museum experience to be as ***compelling*** as Jurassic Park and as ***engaging*** as Universal Studios' Islands of Adventure. There was an immediate disappointment that the existing exhibit consists only of fossils. The content team focused on creating and animating realistic prehistoric sea reptiles to equal the computer generated recreations on cable television. Even so, with Sea Creatures, the visitors were in control of the camera and interaction as they were playing the paleontologist's assistant.
- The experience was capable of being ***persistent***, yet for the short-term nature of the field testing, it was only available at the museum and not with schools and home.

3.5. Content structure: story, play & game

The Power of Water uses key ***story*** lines to illustrate the learning objectives that will be elaborated differently within each venue. These stories drive the different activities within the simulation, focusing the open-ended ***play*** possibilities of the simulation. When guests are challenged to more masterfully experiment with the science, they are provoked into ***games*** to test their understanding of the dynamics of science. This combination of story, play and games is applied to each of the following themes that emphasize unique aspects of the science as carried out within the learning objectives of each venue (figure 9). This cycle reflects the scientific process of fascination, inquiry and experimentation to train the citizen scientist.

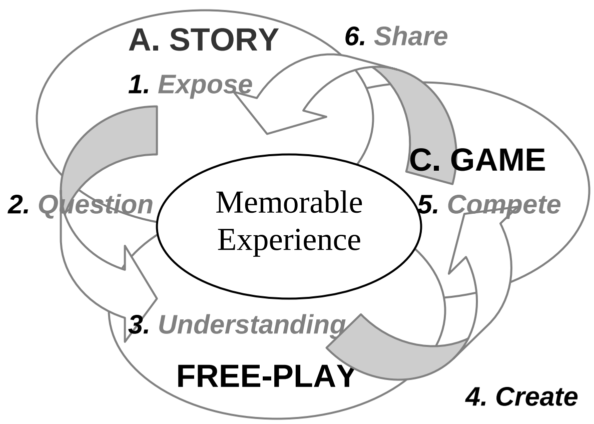

Figure 9. MR ELL story, game and play structure

- ***Learning Objective (story):*** In order to provoke inquiry and spark the imagination so we can teach the mind, the learning objectives are wrapped in the art of story. This provides the hook for molding exploration of the components into a compelling framework to transition curiosity into experience, then into understanding and relevance.
- ***Experimentation (play):*** The real-time virtuality provides for immediate feedback that allows for numerous unpredictable "cause and effect" playful experimentations. Every time the exhibit is experienced, it provides unique variations so visitors can perceive the nuances of the science. Accurate or in some cases perceptually accurate real-time physical modeling allows the user to make decisions with devastating outcomes to gain a deeper understanding of the complex conditions determining consequences; after all, we often learn better from our mistakes than our successes.
- ***Engagement (game):*** Based on archetypal game structures, the users are given compelling objectives with natural physical laws and quantitative results to form the basis of a "good game," providing the incentive for competition and replay, compounding the opportunity for the mastering of the subject matter.

3.6. Sea Creatures Evaluation

The objective of the Sea Creatures evaluation was to better understand if and how a scaled-down version of our Mixed Reality Experiential Learning Landscape enhances a core exhibit. The sampling of subjects was selected from the average traffic on a variety of days.

The data from the field testing, conducted by third party evaluators [5], observed a significant increase in expected enhancements to the exhibit of Dino Digs. The graph in figure 10 shows feelings about the exhibit; visitors agreed or strongly agreed that it increased the entertainment value (88%), encouraged a longer experience (98%), encouraged repeat visits (84%), provided more learning about the subject matter (83%), and sparked interest in visiting similar exhibits (88%).This has significant impact on the overall educational and economic improvement of traditional exhibits without the investment of space, time or cost incurred in capital improvements.

Conclusion

The analysis (cost and user satisfaction) verified that by employing Mixed Reality in an appropriate way, an experiential venue of either education, entertainment or marketing can increase its draw in attendance, increase its value to loyal customers in repeat visits, and increase both the educational and the entertainment value of an experience that leads to higher guest satisfaction. This can be a powerful tool for attracting market share in a highly competitive leisure time market. The fact that this approach produces these results without major renovation, downtime, or space allocation increases income potential while also reducing costs.

With the dynamic nature of the media, it means that new revenue streams can be produced with the adaptation of second gate admission for special events, custom content for hard to reach markets, and scalable, distributed models for rental income. In addition, this model has the potential to be web-enabled to support formal and at-home schooling to boost a museum's core markets. As an added value, it is a compelling marketing tool for promotion and publicity.

Using the basic format of an educational video game, MR enhancements can attract and satisfy diverse age ranges. This creates an almost immediate return on investment by capturing hard-to-attract demographics such as teenagers and older adults. These demographics tend to have a higher percentage of disposable income and MR can help satisfy an unmet need of these untapped markets. The distribution of age ranges that visited the field test exhibit is similar to industry standards. Teens tend to value the entertainment and older adults value the increased depth in the material. MR is showing it can do both.

In order to provide environments that support a lifetime of learning, an experience needs to attract all ages. The data collected mirrors typical attendance in science centers with the current content attracting mainly elementary kids of educated young parents. This is a very limited and saturated market. The ability to attract whole families from diverse backgrounds could easily double the potential attendance as well as provide critical opportunities for a more representative sampling of society.

4. Future Development

With research, maturation and wide dissemination, Mixed Reality will be able to start changing its cumbersome human system interfaces. This change has the capacity to create systemic change in the educational system beyond K-12 compulsory schooling. The future ability for Mixed Reality to go wherever video and GPS reach, such as telephones and PDAs, means the expanse of human knowledge will not be confined to sheltered museums or darkened computer labs. Current projects under development include the Human Experience Modeler where advancing the science of cognitive rehabilitation is not only providing the learning of science, but advancing the science of learning. Mixed Reality, by combining virtual simulation, physical reality and the creative imagination, will enable new applications that melt the boundaries of science and fiction. Becoming a citizen scientist will be more fun than visiting a theme park, with the hope that we all become kids at heart and scientists in mind.

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