Mission: LEAP
Teaching Innovation Competencies by Mixing Realities

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Abstract. Mixed Reality (MR) melts more than boundaries between realities. MR also melts boundaries between disciplines to stimulate innovation. In a project originally sponsored by NASA, the authors of this paper discuss the case study Mission:LEAP, a Mixed Reality Experiential Learning Landscape. In achieving the core objective of building innovation competencies in youth, we had to expand Space STEM education to include the Arts, Media, Design and Humanities to teach innovation competencies. By play-testing a full-scale mock-up, the process also revealed the value of MR in experiential learning landscapes and defined new aspirations and requirements for innovative ways of how we interface with MR environments in free-choice learning venues.

Keywords: Innovation, Mixed Reality, Informal Education, Interplay, Phydgital InterSpace.

1 Inspiring the Next Generation of Innovation

NASA is historically an internationally recognized leader in innovation. The creative leaps in Science, Technology, Engineering and Mathematics (STEM) accomplished from space exploration have inspired the world across all industry sectors. NASA did not become innovative; it was born innovative out of necessity. It was created to radically innovate the US capability to compete in the world quest of space exploration. The Cold War fear to "keep up" soon transformed into the impassioned hope of "human endeavor" to achieve unfathomable feats of innovation. NASA continues to innovate with ambitious goals to accomplish, "what has never been done before; to go where no man has gone before," which makes it an ideal case study for teaching the core competencies of innovation.

NASA's celestial ambition inspired a nation of innovative visionaries who spawned remarkable economic growth. The rapid rise of companies such as Apple, Google and Facebook because of their innovation is equal only to the surprisingly near extinction of venerable American companies such as IBM, Kodak and Chrysler for their lack of foresight of innovation. The consistent and predictable "operational

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excellence" that helped companies to last in the past, will be their systemic downfall in the future [1]. The future, with the anticipated constant change of radical innovation, requires bottom-up and agile processes for the intellectual workforce to be creative, passionate, independent-minded, and enterprising so that they not only anticipate change, but drive change [2]. Innovation skills are not just for the leaders, but for the entire workforce [3]. In a new consumer-driven marketplace, the users play a critical role in the innovation process [4]. Where invention can take just one person, innovation requires adoption by large groups of consumers. This adoption requires an innovation culture willing to change and adapt to new means, methods and unforeseen challenges [5].

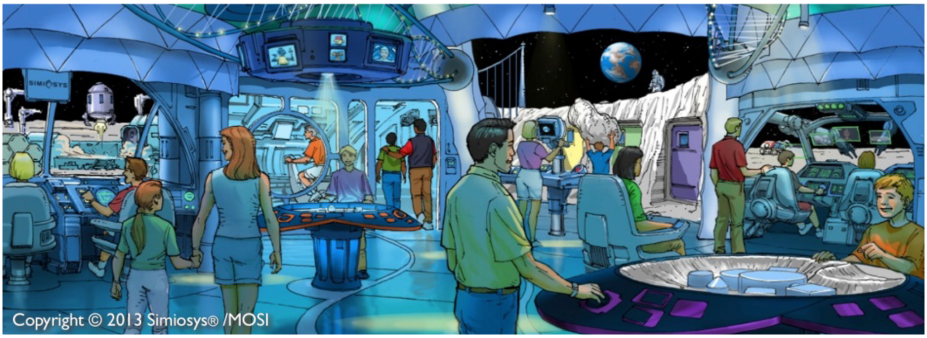

Fig. 1. Concept Rendering, Mission: LEAP (Learning Expedition for Astronaut Pioneers)

2 Is STEM Education Enough to Drive Future Innovation?

How do you prepare today's youth to passionately dive into the unknown and unpredictable future of innovation? Can NASA inspire the next generation innovators? Our goal was to create a Mixed Reality (MR) Experiential Learning Landscape (ELL) that would enlighten the public on the importance of how deep space exploration can teach core innovation competencies. A public that is more innovative can stimulate the speed and ease of the innovation flow that the economy needs for survival [6].

In the 2011 Atlantic Century Report, the United States ranked fourth among industrialized nations in innovation-based competitiveness and ranked last in improvement in international competitiveness and innovation capacity over the last decade (Atkinson & Andes, 2011). Apparently, "the scientific and technological building blocks critical to economic leadership have been eroding at a time when many other nations are actively laying strong foundations in these same areas" (Dept of Commerce, 2012, p. v). With such reports, the current emphasis and funding of STEM education is understandable, but is it enough? While STEM education provides the foundation of invention, the core competencies of innovation rely on soft skills and attitudes, such as fostering creativity, imagination and passion to imagine the possibilities rather than just developing the capabilities. These are competencies that are aligned more with the Arts, Media, Design and the Humanities more than STEM [7]. The economy does not benefit until inventions are transformed into marketable innovation.

The problem is while STEM education is solidifying the foundations for innovation, it is not necessarily fostering the passion and creativity necessary to innovate that is critical for market diffusion. The creative expression of ***art***, the critical problem-solving of ***design***, the compelling impact of marketing (***media***) and the understanding of the human experience (***humanities***), drive the success of products. While Federal and state mandates continue to pressure K12 educators to teach-to-the-test STEM knowledge, they cut the creative skills training of the Arts, Media, Design and Humanities (AMDH) that are critical to achieving the economic rewards of innovation [8]. In addition, corporate culture and training that often focuses on eliminating error, reducing variance and increasing operational excellence, particularly in highly regulated industries, also inhibit creativity and innovation [1]. New approaches to education and professional development are necessary to prepare the next generation of innovators essential for economic success.

3 Convergence of STEM and AMDH to Learn Innovation

NASA's unique position spans civic, academic and commercial interests while tapping both technical and creative fields to produce future innovative solutions. NASA has also become an expert of the larger innovation process, managing both the invention and adoption of the innovation. To complete the cycle, NASA's technology-transfer program bridges innovation back to civilian life where it is designed to stimulate the future economy. So what distinguishes Space STEM from other STEM professionals? Deep space exploration is dependent on a state of constant change driven by persistent innovation that, in turn, depends on innovation competencies that support the legacy of discovery. With this perspective, the space innovation experience can inform the learning experience and the preparation of our overall future workforce.

When interviewing Space STEM Professionals about their role, we were struck by the fact they had the enthusiasm of creative artists. NASA space professionals emphasized their dreams, passions, collaboration, creativity and imagination. In response, our creative design staff were just as passionate and fascinated with the possibilities of space STEM. These shared professional interests and passions reinforced the cross-disciplinary synergy that is at the core of innovation collaboration [9]. The interdependencies between STEM and AMDH drove the design of our learning landscape. STEM and AMDH are in fact, "two sides of the same coin." To guide the design, we crafted a series of antithetical aphorismic stanzas describing transdisciplinary collaboration that was inspired by Pablo Picasso's quote, "Art is a lie, that reveals the truth."

Science *is the truth that unveils the myths;* ***Art*** *is the myth that unveils our truths.*
Technology *imagines the extension our abilities;* ***Media*** *is our ability to extend our imagination.*
Design *is the dream of the achievement;* ***Engineering*** *is achieving our dream.*
Mathematics *is the expression of insight;* ***Humanities*** *is insight of expression.*

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4 From Innovation Expert to Novice to Future Expert

We asked Subject Matter Experts (SME) from the highest levels of research at JPL to operational staff at Kennedy Space Center about their pathway to Space Exploration. Many shared a similar frustration of their youth in following their life's dream because, at the time, there were no explicit paths to become an astronaut.

Every space professional we interviewed remembered a similar time when they were first inspired as a child, whose youthful experience still drives their passion today. How can we capture that experience to inspire kids today and motivate learning about their role in innovation? Each of those different experiences of NASA personnel consistently described three characteristics that defined their passion today:

REAL (hands-on): The childhood experience represented a tangible engagement with the reality of STEM/AMDH principles to achieve a satisfying result (taking apart an appliance, watching birds, designing something or blowing it up, etc.). Such experiences emphasized the physical, hands-on nature of learning innovation through curiosity, creativity and experimentation.

RELATIONAL (heart-felt): The experience was with a mentor or peer group (family, class, group leader, etc.) who stoked their curiosity and guided a memorable experience they couldn't have had on their own. Such experiences emphasized the important role of family learning, passions and group (or team) interaction in experience-based venues.

RELEVANT (head-strong): The experience opened their eyes (and mind) to so excite them about a concept that they could imagine themselves doing it for a career ("people can do this for a living?") providing them with a lifetime of wonder. Such experiences emphasized the importance of role playing and the sense of belonging to a larger cause with a meaningful purpose and experience.

A community, family-based learning center is an ideal place for bringing together these aspects of experiential learning. However, so many museum exhibits are one-time experiences that do not span the breadth of experience, nor the knowledge of space or the imagination of the child. These experiences don't change with the time, nor expand beyond the walls of the museum. The experiences are over-simplified, pre-programmed, individual experiences that don't invite that child-parent interaction or problem solving skills [10]. It's not the knowledge that will excite that child about a career in space, but it is stoking their imagination and providing the tools of the trade for them to jump in and have a real, relational and relevant experience. We need to make a memorable experience similar to the childhood memories of the space professionals to make a lifetime impact. This experience challenged even the best practices of museum exhibitory forcing us to innovate to teach innovation.

5 Transporting Visitors into Their Own Innovative Future

To inspire visitors about the future of innovation, we find ourselves where science meets fiction. Mission: LEAP, a Learning Expedition for Astronaut Pioneers

(Fig 1 & 2) is a simulated colony set in the future to spark the imagination of young kids with a vision of their future life as an astronaut. Visitors arrive at a fully operating, simulated habitat to make the experience real, relational and relevant. They then explore opportunities to initiate different levels of innovation by honing their creative skills.

To start, we picked the year 2075 when living in space may be commonplace and astronauts will be more than scientists, pilots, engineers or doctors. Venturing into long-term, deep-space exploration, astronauts will be chefs, artists, media producers, therapists, farmers, entrepreneurs and architects. This future involves creating colonies that will require us to reinvent life as we know it to survive (Fig 2). Without the pristine ecosystem of earth's atmosphere, we will rely on new inventions of STEM to become Techno-Species, as James Cameron describes future space explorers, who are dependent on technology for survival.

The Mixed Reality Experiential Learning Landscape becomes a hybrid of a visceral theme park and a dynamic video game [6] with social networking capabilities. The science-based fantasy challenges the participant's creative imagination and problem solving skills beyond their current experience and abilities. Our attempt is to create the hardest fun the students ever had. As frustrating and ambiguous that difficult creative problems can pose, using the interplay of story structure, game mechanics and play testing makes each challenge more motivating by being fun and social [11].

6 Innovation PlayTank: Transforming Idea to Innovation

Museums offer an ideal venue to augment a person's formal education and to foster the development of innovation competencies with creative hands-on activities. The challenge lies in telling such an infinite story in such a finite space. The typical museum exhibit falls short of providing the breadth and depth of experience to teach such a broad spectrum of innovation competencies. Instead, many museums seem to re-emphasize school standards in a limited, "hit and run" level of interactivity. An exhibit about future innovation should embody a living example of innovation and constantly change and challenge visitors with new learning opportunities. But like many other institutions, when they sense the need for fundamental change, "museums remain enmeshed in a network of interdependencies that undercut their ability to innovate" [15].

Taking a cue from industry and academia, we set up a rapid prototyping facility (Fig 2) called the Innovation PlayTank (versus Think Tank) to make creative leaps in demonstrating innovation. By taking the messy creativity and unpredictable experimentation out of the arena of "operational excellence," the PlayTank avoided defeating criticisms and resistance to change. To satisfy the museum, designers and client (NASA SMEs), we produced four iterations of the full scale exhibit collecting feedback to make improvements on each monthly iteration using subjects of all ages. A series of exploratory play-tests entailed expert observations, survey responses and a focus group.

Fig. 2. Traditional hands-on phenomenon based experiences were combined with virtual game-based activities to extend play, encourage collaboration and deepen learning

Over-thinking and over-planning of complex, creative ideas such as experience design can kill the most promising of experiments. The best way to validate entertainment value and usability is to try it out on an audience sooner rather than later. The practice of "play-testing" is to create experiments much like a child creates play on the playground-- expending the least effort for the most impact and immediate response. The practice was as intense and diverse as a "think tank," but the full scale mock-up was more like a playground. This process became to be known as the Innovation PlayTank (versus think tank).

The Innovation PlayTank took form at the business incubator at the UCF Institute for Simulation and Training. In a 3000 square feet, high bay laboratory the exhibit concept design was fully blocked out with the exhibit floor design and with minimal lighting, audio and scenic elements created a sense of place on the moon with the earth setting over the crater wall. Each station at first used free online games to represent the simulation. A Skype connection represented a social network between stations. Live inter-actors provided the over arching premise and story. Placed between computer stations were simple physical exhibits such as sandbox demonstrating lunar cratering; a salad bowl and air ducting on foam core to represent a space suit; water bottles and ping-pong balls representing physical monitoring stations. In each iteration, the role-playing became more sophisticated, the floor plan evolved, the activities became refined and the virtual content became more specific and and physical. Beyond the extensive creative development and exchange, there were critical insights and "lessons learned" (below) into new requirements for experiential venues that were required for us to improve the Mixed Reality interface.

Be social to be successful: Challenging experiences done alone became frustrating for participants, while the same experience with somebody joining them, became "fun." The aspect of being relational became the difference between success and failure. Ease-of-use concepts to eliminate the frustration would actually kill the fun. Instead, we needed to create not an ***interface*** between computer and human, but an ***InterSpace*** between people and their activities to emphasis the face-to-face interaction between people.

Make Mixed Reality as ONE world. The use of a single virtual display in a physical venue consumes the attention of a single user into the virtual presence beyond. This single screen decreasing their awareness of their interpersonal or physical surroundings. This virtual-real chasm in their sense of presence prevented cross-over activities between real and virtual spaces detracting from the effectiveness of mixing realities. Leveraging multiple screens provided emphasis to the space between the displays, versus in the display themselves. This allowed for a more spatial awareness enhancing the InterSpace between people. We needed to start with the physical world and embed or project the virtuality in or on the reality to make sure we did not lose the social in lieu of the virtual.

Make it real. The more realistic the interaction, the more the user enjoyed, engaged and believed in the experience. Allowing the guests to engage with real tools of the trade, was dramatic in its ability to transport audiences. Virtualizing real equipment should take priority over trying to make equipment virtual. The physical haptics engaged the learning experience more.

Make it unreal. The power of experiential venues is the ability to "be there" with peripheral stimulus with all the senses. Just a small amount of peripheral and tangential perception can stimulate the imagination with sounds, sights, smells and feelings. Leaving more to the imagination directed with well orchestrated tangential, multi-sensory stimulus can better transport their presence to places that you could never fabricate real or virtual. However, no effort to the design immersive sensory illusion can be detrimental to the experience.

Smiling is the best learning assessment tool: While video games can have multi-players, the typical game design becomes co-active, versus socially interactive event. To stimulate the relational aspects of the learning event we emphasized the face-to-face visual contact across the playing field or via teleconferencing. This provided critical cues for the mentor or docent to exchange joy, inspiration, comprehension or frustration.

The best part of reality are the living. The coolest displays of virtuality and exhibitory were ignored after the first few minutes. To stimulate longer term engagement and inter-zone interaction, took significant effort technically. However, the efforts of a single live inter-actor to make connections, stoke exploration, excite challenges transformed the experience. We soon needed to develop a networked system that allowed a single interactor to more readily instigate group interaction, generate a colony-wide emergency, puppet a virtual robot, or monitor all displays via teleconferencing, providing a powerful and salient experience. Technology could never replace a live "experience conductor," but technology can significantly augment their abilities. Without the live interactor, other exhibits equated to mere vending machines of learning with little engagement, depth or duration.

Competition is a double edge-sword. Game points dramatically increase competitive engagement and emotional investment. However we saw, if competition and point making is not uncheck or monitored, competition can quickly lead to cheating, spiteful aggression and panic that can dramatically interfere with the fun and the learning. In a face-to-face experiential venue, cooperative play as in the case of an emergency response or competing against a non-present virtual competitor increased motivation, stimulated learning and providing more enjoyment.

The GUI gets in the way. Every example of a "Drag and drop," or "point and click," GUIs needed to be replace with "cause and effect" responsive simulations. This is because the abstraction of the GUI required too many instructions, demonstration and rule sets within a physical simulation venue, which led to decreased understanding, fun and engagement. Guests wanted immediate interaction and stimulus for "trial and error" feedback loop or "play." Virtual simulations and physical "sandbox" type of phenomenon-based experiments (with intuitive and naturalistic interaction and immediate tangibility) significantly out performed the more push-button computer graphic games.

In creating a prototype of this off-world colony experience to a high level of engagement, we had to challenge the common physical interfaces of traditional museums and question the validity of the common GUI interfaces used in virtual interaction. The series of iterative play-testing experiments provided critical new requirements of the next generation mixed reality experience for informal education facilities.

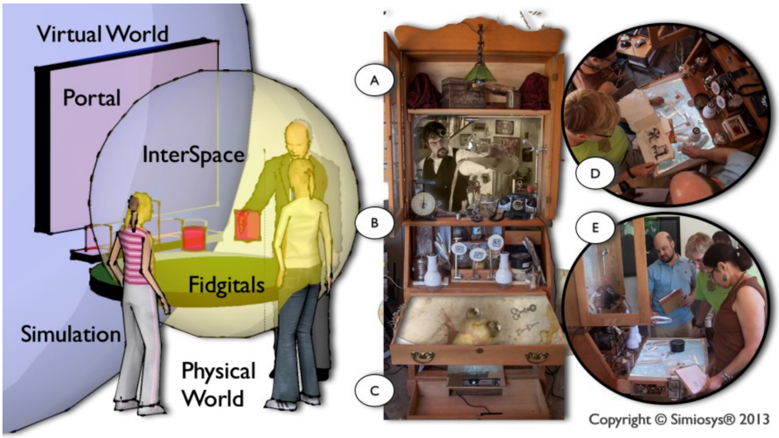

Fig. 3. Phydgital InterSpace prototype play-testing at an Innovation PlayTank

7 Phydgital InterSpace Melting Boundaries with Mixed Reality

The Mission: LEAP mock-up provided critical requirements for innovating immersive Mixed Reality interfaces for museums. Museums are experiential venues whose entertainment value comes mostly from social face-to-face interactivity with hands-on engagement. The use of a physically dynamic objects in between people is the most rapid, intuitive way to invite participation, escalate engagement and increase the desire to challenge users. A ball, a sandbox or a water fountain are simplest examples that achieve this state of engagement with kids. With these examples, there is an immediate attraction, intuitive interaction and the sensory feedback that provides satisfying and repeatable social play. We needed to achieve the same in a interactive station.

Our solution was a Phydgital InterSpace that starts with the physical object and environment (Fig 3) and embeds physical artifacts with the virtual life so that they can be intuitively manipulated within a shared space between participants and virtual worlds. This object becomes the "Phydgital," the physical/digital object that you fidget with. This works in tandem with the shared tangible space in between participants and virtual portals that we call the "InterSpace." Once we used multiple screens and physical objects, the tendencies of the users was to not be consumed by the virtual presence beyond any one virtual portal interface. This concept combines the intuitive interaction of physical reality and leverages the dynamics of the virtuality.

The first prototype of the Phydgital InterSpace was play-tested in an experiment to make a curio cabinet come alive for use in a history museum or science center (Fig 3). In the cabinet a fictional, virtual biologist was creating genetic mutants and came to us within an image of the mirror that capture his presence from years before (A). His experimental biology tools became Phydgitals (B) that could be picked up and used in his vernal pool to feed, kill or infect swimming creatures (C), which was a virtually projected in a drawer representing a watery ecosystem of the biologist's creation. Other physical artifacts, like his journals provided secrets and clues as to the mystery of this curious display. Both virtual displays, one computer generated and the other video captured represented extensions of the physical space. The vertical reference portal provided character interaction through video while the horizontal simulation portal provided immediate cause and effect, trial and error interaction and feedback. Designed as a time-based puzzle, participants gathered around the vernal pool to experiment with the phydgitals to determine if they should save the creatures or euthanize to prevent contamination. No instructions were provided. However, guests naturally and instinctively went through a loose scientific process to figure things out. The frustration and ambiguity of the open-ended problem solving (there was no "right" answer) seemed to increase the entertainment value, because the participants could choose their own creative solution. Objects were so curious and responsive, while the social interaction prevented the challenge from becoming to frustrating.

The simulations provide repeatable play and intuitive interaction that can provide an opportunity for creativity. This proved to create an escalation of inquiry based learning that naturally followed the scientific process. These tests will inform the next generation of Mission: LEAP and push the standards of museum design.

8 Conclusion

Our future economy is dependent upon the competitive edge of creative innovation. To that end, we can't over-emphasize Science, Technology, Engineering and Math at the cost of the loss of the Arts, Media, Design and the Humanities. In inspiring the next generation of innovator, neither can we myopically assess the retention of knowledge without evaluating the application of knowledge with skills creative and attitudes. We can't think that virtuality can do everything that reality or imaginality can achieve in learning [16] and need to innovate new paradigms in interface design in mixing realities. This act of innovation to help teach innovation emphasizes the importance of experience-based education venues as real world laboratories of learning and experimentation need to evolve and innovate with the times.

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