Games for Learning in Embodied Mixed-Reality Environments: Principles and Results

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Abstract

Mixed-reality learning platforms are coming of age. We review several studies that demonstrate increased learning when students are in embodied, mixed-reality environments compared to learning in regular instruction environments where teacher and content are held constant. Two scenarios are described in-depth and a set of gesture-based design principles is presented. Embodied, mixed-reality environments can support significant gains in learning because multiple sensori-motor systems are activated when learning. In addition, classroom discourse is more focused in these collaborative environments and language may serve as a mediating variable for change.

What is an embodied mixed-reality environment?

The Situated Multimedia Arts Learning Lab (*SMALLab*) is an example of a mixed-reality learning environment. *SMALLab* is an educational platform that engages the major modalities (i.e., the sense systems including visual, auditory, and kinesthetic) that humans use to learn. The platform is considered embodied because it is kinesthetic and based on physical movement. It is easy to enter/exit because there is nothing to strap on or wear. *SMALLab* uses twelve infrared motion tracking cameras to send information to a computer about where a student is in a floor-projected environment. The floor space is 15 x 15 feet and the tracked space extends approximately seven feet high. Students step into the active space and use a “wand” (a trackable object) that allows the physical body to function like a 3D cursor in the interactive space. The environment also allows for multiple students (up to four) to be tracked simultaneously. With turn-taking, entire classrooms with 30 students are able to physically experience a learning scenario within a typical class period. Students outside of the active space sit around the open periphery and collaborate with each other and with the active students.

We believe that the introduction of the affordable *Xbox Kinect* system will greatly advance the field of embodied learning. Research into the type of learning afforded by motion capture (or gesture control) technologies in classrooms is direly needed. It is important to note that gesture-based learning is not content constrained. We have studied learning in embodied environments in several different content domains, including language arts (Hatton, Birchfield, & Megowan, 2008), science, technology, engineering, and mathematics [STEM] content (Birchfield & Johnson-Glenberg, 2010; Johnson-Glenberg, Birchfield, Savvides & Megowan-Romanowicz, 2011; Tolentino, Birchfield, Megowan-Romanowicz, Johnson-Glenberg, Kelliher & Martinez, 2009), and special education with a focus on individuals with Autism Spectrum Disorders (Savvides, Tolentino, Johnson- Glenberg & Birchfield, 2010).

Learning Gains

A previous geology study examined student learning related to earth's "layer cake" morphology that is formed through complex, dynamic processes (Birchfield & Johnson-Glenberg, 2010). Many of our in-school studies use a waitlist control group design, i.e., one group of students will go through the *SMALLab* intervention first and one group will go through regular instruction first—then the order of intervention will switch. Three invariant tests were administered. Statistically significant learning gains were seen whenever the students were in the embodied *SMALLab* learning condition. In the regular instruction condition, students created hands-on paper timelines and discussed the dynamics of geology in small groups. Thus, it was an active and appropriate control that also resulted in learning gains. However, the gains seen in regular instruction were not statistically significant. We propose three primary reasons for the consistently higher gains whenever students are in a mixed-reality, embodied environment: embodiment, collaboration, and novelty, as well as the two important "mediator" variables of language and gameplay.

Embodiment and Collaboration

Multiple research areas now support the tenet that embodiment is a powerful underpinning of cognition. The various domains include (but are not limited to): neuroscience and mirror neurons (Rizzolatti & Craighero, 2004), cognitive psychology (Barsalou, 2008; Glenberg & Kaschak, 2002; Glenberg, 2010), linguistics (Lakoff, 1987), math (Lakoff & Nunez, 2000), gesture (Hostetter & Alibali, 2008), and dance (Winters, 2008). Glenberg (2010) contends that all cognition comes from developmental embodied interactions with physical environments. It follows that all thought—even the most abstract—is built on the foundation of physical movement. Our position regarding embodied learning is that the more modalities (sensorimotor systems) that are activated during the encoding of the information, then the crisper and more stable the representations will be in schematic storage. These crisper representations, with more modal associative overlap, will be more easily recalled. Better retrieval leads to better performance on assessment measures. If gestures are another modality—and they emerge from perceptual and motor simulations that underlie embodied cognition (Hostetter & Alibali, 2008) —then creating an embodied learning scenario that reifies the gestures (motor traces from and to cognition) should be a powerful teaching aid.

In addition, all of our scenarios rely on collaboration. Collaborative learning generates significantly higher achievement outcomes, higher-level reasoning, better retention, improved motivation, and better social skills (Johnson and Johnson, 1984; Johnson and Johnson, 1989; Johnson and Johnson, 1991) than traditional didactics. We have found that more focused, education-oriented language and productive gameplay are two constructs that fall out of well-designed collaborative experiences.

Mediators of Language and Gameplay

We have pilot evidence from teacher and student discourse in a chemistry experiment with three high school classes (Johnson-Glenberg, Birchfield, Koziupa, & Tolentino, submitted) supporting that language is affected by the environment. When in *SMALLab*, 100% of student discourse was on-topic and related to the content to be learned. When students were in small groups working on a project-based, wet lab lesson only 66% of the content-per-discourse-turn was task-related. Language in mixed-reality environments appears to be more on-topic and learning directed; this may be related to the collaboration built into the design. In addition, students know they will shortly be in front of the entire class performing. Because all students will eventually be "center stage", they are extremely motivated to get it right. When students have been placed in small groups they are motivated to not let down their peers. Using principles from game design we have kept errors somewhat "low stakes". It is not egregious to make mistakes in *SMALLab*, students receive immediate visual and sonic feedback regarding the veracity of their choices and errors can be quickly corrected. Thus, it is safe to fail. It is necessary to fail early on so that observers learn from the previous mistakes. Nonetheless, it is human nature to want to perform without mistakes and we think this motivates students to attend to the content.

Our hypothesis is that there is something about the affordances of a mediated, co-located collaborative process when combined with gameplay that alters language-use in a classroom. The on-topic language, in turn, affects learning gains. The learning, in turn, affects the flow of the gameplay and these variables continuously interact to create a powerful learning loop that is extremely motivating for students.

Learning Scenario 1 – Disease Outbreak

All of our scenarios rely heavily on gameplay (Gee, 2007; Salen & Zimmerman, 2003). At the School of Arts, Media, and Engineering at ASU, we have assembled a multi-disciplinary team that creates scenarios that end with a game. Often students are placed into small teams for benign competition ("Which team can make the solution neutral in the fewest moves possible?"). We include two examples of scenarios in this paper and encourage readers to explore more online at www.*SMALLab*learning.com.

The Disease Outbreak scenario was developed with a veteran science teacher in an attempt to dispel several misconceptions surrounding disease transmission. Since we were attempting to model a complex phenomenon that would include many different variables, we decided to constrain the system model and we focused on: 1) the difference between bacterial infections and viruses, 2) the difference between antibiotics and vaccines; 3) antibiotic resistance; 4) symptomatic and asymptomatic carriers, and 5) concept of limited resources (e.g., medicine supply, nutrition). We considered how we might leverage the unique features of a mixed reality environment to engage the students and motivate them to participate. The scenario was designed so that the students would not only develop an understanding of how a disease could be transmitted in a closed system, but so they would be able to generalize their new insights to other systems as well.

We are proponents of student-created content and have worked with students to create original pieces of complex media. In this study, we needed to start gradually. We asked students to first create their own avatars by using an avatar creation website (doppleme.com). They saved their images as .gif files and submitted them to the teacher. The avatars were distributed around the perimeter of the *SMALLab* floor projection so that students could sit behind them and manipulate them during play. This ownership proved to be very engaging; indeed, all students who did not have a self-created avatar on the first day of the study made certain they had created one by the second day. To engage the students even further and create a sense of urgency, each avatar's health would reduce over time until a "skull and crossbones" appeared (Figure 1). The health reduction speed was an element that could be adjusted for each run of the simulation. An inner ring of color surrounding each avatar indicated whether it was healthy (white), symptomatic (red), or asymptomatic (yellow). To encourage the students to move within the

SMALLab space, we placed two centrally located “Supply” icons in the center of the floor; one represented medicine, while the other represented nutrition or water (Figure 2).

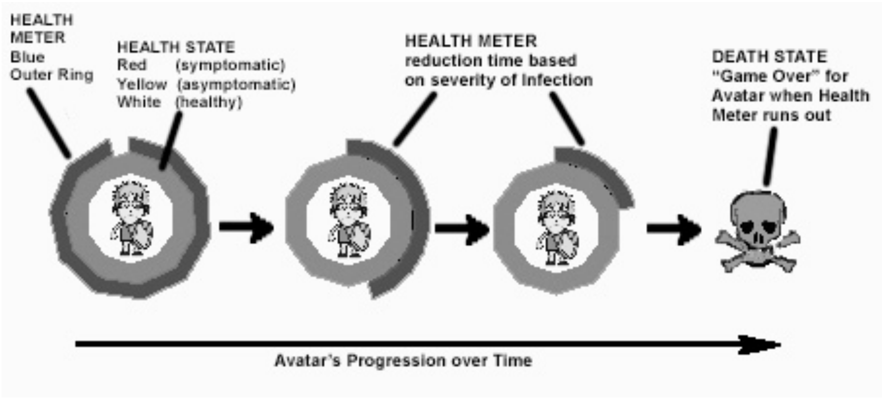

Figure 1. **GamePlay Mechanics for Each Avatar**

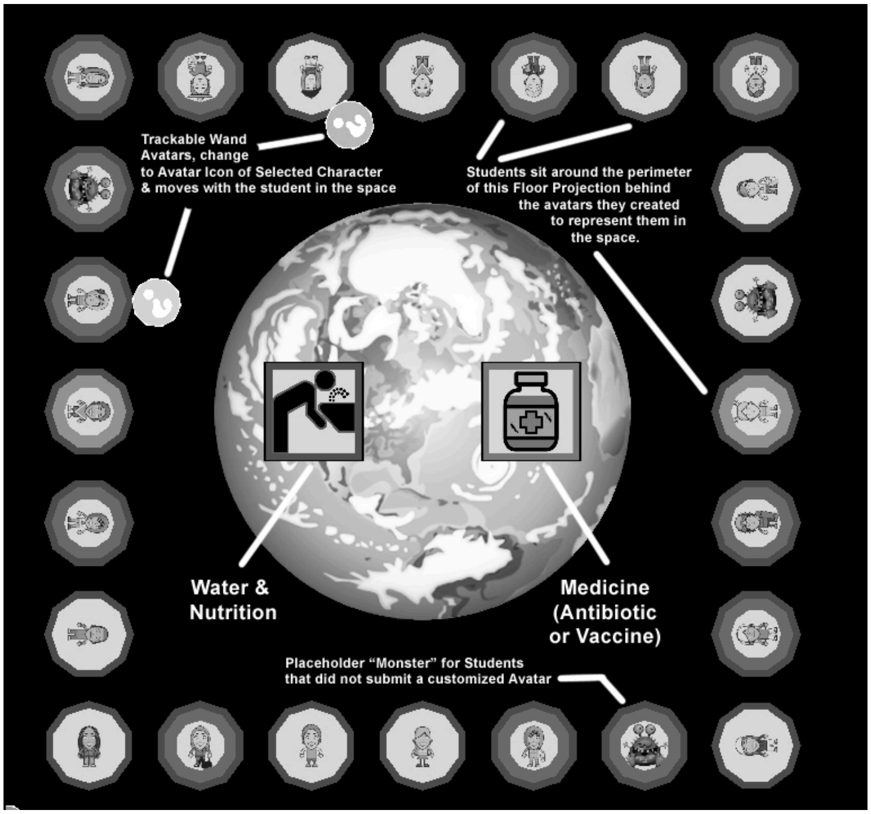

Figure 2. **The floor projection for Disease Outbreak. Avatars ring the outside.**

One design challenge was to present a large amount of information in the space without overwhelming students. We chose a framework wherein we gradually increased the complexity of the information being presented in the space as stages were mastered. Thus, different “levels” of complexity were presented when the teacher ascertained that students were ready. When students hit certain “targets”, or collaboratively made and agreed upon a correct observation, new components were introduced that made the game more difficult. In this waitlist (or crossover) design, each group spent three days in SMALLab. On the first day, the teacher as facilitator encouraged the students to deduce the method of transmission, and to explore the types of interactions that were possible in the space. This included selecting or "picking up" an avatar, and bringing it to either the water or medicine icons in the center of the space. On the second day, students deduced that avatars with “red” or “yellow” inner disks would have a faster rate of decline for their health meter. All instruction followed the model of inquiry-based science learning. On the third day, further complexities were introduced into the system, e.g., limiting the supply of medicine, hiding the asymptomatic carrier symbol, or setting a threshold for antibiotic resistance. The teacher would simply tell the students that something was now being modified in the simulation, and that they would have to discover what had changed. Finally, we would vary the infection type to be either viral or bacterial (such that a “vaccine” would need to be administered prior, as opposed to an antibiotic being given after the illness was present). In the controlled study the two groups were matched at pretest. See Table 1 for a description of the design. Group 1, the one that first received the SMALLab intervention made significantly greater learning gains by the midtest compared to the group that received regular instruction matched for content and teacher (Johnson-Glenberg, Birchfield, Koziupa, & Tolentino, submitted).

Table 1: Experimental design

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Group 1	**Pretest** *SMALLab*	*SMALLab*	*SMALLab* **Midtest**	Regular	Regular	Regular **Posttest**
Group 2	**Pretest** Regular	Regular	Regular **Midtest**	*SMALLab*	*SMALLab*	*SMALLab* **Posttest**

On day four, the intervention switched; by posttest, the students in Group 2 receiving *SMALLab* demonstrated statistically significant gains compared to the regular instruction group that displayed a very small effect size.

Learning Scenario 2- Quest to Learn’s PUSH.

Quest to Learn (Q2L) is an innovative 6th-12th grade school in New York City that has a *SMALLab* structure permanently installed in the school. The public charter school has been designed to help students bridge old and new literacies through learning about the world as a set of interconnected systems. *SMALLab* scenarios are integrated into existing curricula. Similar to the ASU team, Q2Lteachers work closely with game designers and instructional technology specialists to create engaging, self-motivating content for the students. The brainstorming sessions with teachers help to define a learning goal that is often inspired by a common misconception. Here we describe PUSH an embodied scenario designed to explore concepts surrounding Simple Machines (a standard covered by Q2L 6th grade math and science domain called “The Way Things Work”).

PUSH was designed specifically to create a game-like learning experience through collaboration and embodied play. In PUSH, students work in groups of 2, 3, or 4 to help a group of digital creatures (reoccurring through the curriculum) called Troggles push an object (i.e., a hat) up a hill. Figure 3 shows the hat, Troggles, and the white lines representing the incline. Students stand over the image and maneuver their wands in a "pushing" motion to exert force and get the hat to the top of the incline. They receive immediate visual feedback about Newtons used. The scenario is extremely embodied in that students' muscles feel fatigue as the 'work' continues. When the top is summited, the Troggles jump for joy and high-five each other. The learning is accompanied by worksheets, and students discuss hypotheses about how work, force, distance, and angle of incline relate to each other. An experienced teacher will find moments during PUSH to take advantage of opportunities for learning and reinforce the fundamental concept of mechanical work.

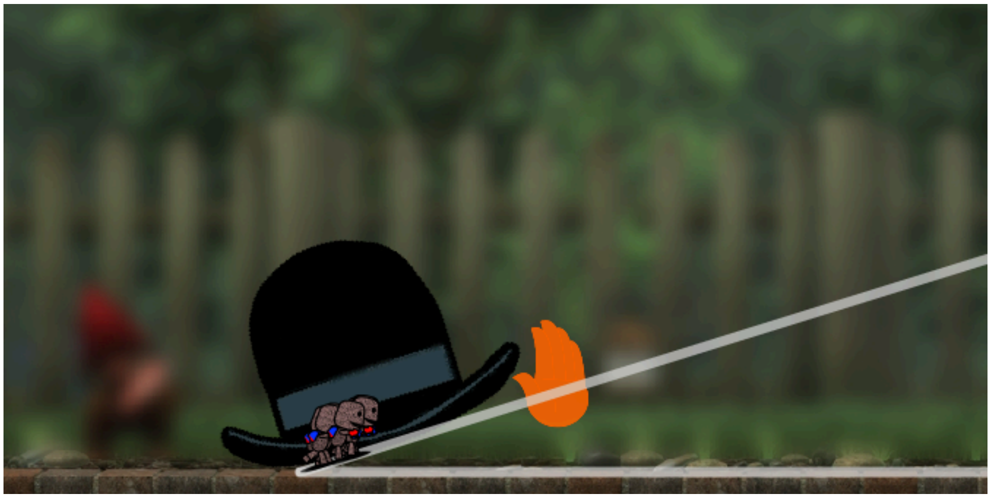

Figure 3. **Troggles pushing a hat up an incline.**

Design Principles

When designing for embodied, mixed-reality environments, we strive to better understand the scope and role of embodiment in these emerging learning environments. We have developed a set of design principles intended to frame the realization of embodied learning experiences in computer-mediated environments (Birchfield, Johnson-Glenberg, Megowan-Romanowicz, Savvides, & Uysal, 2010) These principles apply to the design of interactive experiences, not simply to the affordances of a given technology. Specifically:

1. Direct Impact - Learners' physical actions should have a direct and causal impact in the simulated environment.
2. Map to Function - A learner's gesture should closely align with its function and role in the simulated environment (e.g., physical throwing gestures should align with throwing actions in the simulation, waving a wand along an angle should align to the projected object moving along same angle).

3. Human Scale - Computer interfaces should support movement on a human scale (e.g., degrees of freedom, size and speed of a gesture).
4. Socio-Cultural Meaning - The communicative aspects of human presence and gesture should be accounted for (e.g., human co-location affects learning interactions, the cultural meaning of a gesture, the information conveyed by a gesture needs to be addressed).

Conclusions

Learning in embodied, mixed-reality environments is novel and engaging for students, but does that environment have a significant impact on the content being learned? We have published several studies that support this contention; however, we also acknowledge that it is difficult to run rigorous, controlled studies. Real world classrooms are extremely complex environments where peripheral subject variables like a teacher's comfort level with technology can produce outsized effects on learning outcomes. It is a challenging experimental world for those trained in traditional inferential statistical analyses because it is difficult to capture causal factors in mixed-reality environments. Statistical tests using traditional methods are made more powerful when a large N is used, however, the current, hardware-heavy motion capture environment is stationary and only one physical classroom in the school can be used. It is difficult to do hierarchical linear modeling with so few classes in a building covering the same content. Large N studies have been elusive and we have not been able to adequately tease out the unique and shared amounts of variance explained by the five variables mentioned earlier. Indeed, there may be more explanatory variables beyond these five: 1) embodiment, 2) collaboration, 3) novelty, 4) language use, and 5) gameplay, e.g., motivation and individual differences (i.e., prior knowledge, students' comfort with technology) may prove to be extremely powerful predictors of learning in these environments as well.

The one-room constraint will surely change with the advent of affordable skeletal-tracking input devices (e.g., the *Kinect*). At this time, educators and game designers creating serious content in mixed-reality spaces can design for the environments keeping mind that engagement will probably be enhanced and language will be more on-topic when students are in embodied, collaborative mixed-reality environments. We believe that the comparatively larger learning outcomes we have seen may be facilitated (mediated) by game-like components and more on-topic language use, but we do not know this conclusively, via one degree-of-freedom tests. We cannot say which variable explains the *most* variance. For now it may be enough to design with all variables present and optimized as more refined methods of assessment and delivery begin to emerge. We sincerely believe that embodied, mixed-reality environments hold great promise for the future of learning.

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