Serious Games in Embodied Mixed Reality Learning Environments

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Abstract: Four projects are presented that focus on the intersection of mixed reality learning and embodiment. Here we discuss four games designed to promote health and science education. All the games represent the vanguard of motion capture and skeletal tracking technologies for facilitating learning in a collaborative and exploratory environment. "Feed yer Alien" is a multi-user game created to educate younger students about nutrition. HALY is a yoga-based stress reduction scenario using a touch sensor glove. "MEteor" uses a laser-based motion tracking system and body-metaphor-based interactions to instruct in planetary astronomy. Finally, "Outbreak" is a group collaborative, systems-thinking game in the domain of disease transmission.

Presentation 1: Two Games for Health: Alien Health (nutrition with motion capture) and Yoga/Color Stress Reduction (mixed reality)
Mina C. Johnson-Glenberg and Julie Cruse

What is a technology-supported, embodied learning environment with motion-capture (TELEM)?

The Situated Multimedia Arts Learning Lab (*SMALLab*) is an example of a technology-supported embodied learning environment with motion-capture, a TELEM. *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. *SMALLab* uses 12 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 nine feet high. Students step into the active space and grab a "wand" (a rigid-body trackable object) that allows the physical body to now function like a 3D cursor in the interactive space.

The environment allows for co-located collaboration among the active students because four can be tracked at one time, but, more importantly, the other students sitting around the perimeter can also be engaged in the situated learning as they discuss with each other or call out testable hypotheses. For over eight years our lab has been exploring the boundaries of motion capture as it relates to K-12 and informal learning. We have recently been porting over the floor projected *SMALLab* scenarios into vertical wall projected interfaces so that Microsoft's *Kinect* sensor can be used.

The Promise of Embodied Learning. Human cognition is embodied cognition. This means that cognitive processes are deeply rooted and come from the body's interactions with its physical environment (Wilson, 2002). The role of embodiment in learning has been demonstrated in many domains including neuroscience (Rizzolatti & Craighero, 2004), cognitive psychology (Barsalou, 2008; Glenberg & Kaschak, 2002; Glenberg, 2010), math (Lakoff & Nunez, 2000), gesture (Hostetter & Alibali, 2008), expert acting (Noice & Noice, 2006), and dance (Winters, 2008). Pulvermüller and Fadiga's (2010) review of fMRI experiments demonstrate that when reading words related to action, areas in the brain are activated in a *somatotopic* manner. For example, reading "lick" activates motor areas that control the mouth, whereas reading "pick" activates areas that control the hand. This activation is part of a parallel network representing 'meaning' and shows that the mappings do not fade once stable comprehension is attained. That is, these motoric codes are still activated during

linguistic comprehension in adulthood. In addition, increasing evidence in the study of gesture suggests that gestures facilitate speech about mental images (Hostetter & Alibali, 2008). Gesture may serve as a *cross-modal prime* to facilitate retrieval of mental or lexical items. If the physical movement primes (readies) other constructs (like language), then learning via movement may add an additional modality and prime for later recall of knowledge.

Our embodied learning hypothesis. Much content in western education is taught using abstract symbols, namely the symbols of language (words and syntax) and the symbols of mathematics. If the understanding of these symbols is not grounded on something outside of the system of symbols themselves, then it is difficult for many students to truly comprehend the meaning of the content. Bodily perception and action, and the experiences based on perception and action (Barsalou's perceptual symbols (2008) provide a mechanism for grounding). The scenarios designed by our lab are created to enlist as many relevant modalities as possible during the encoding stage, and to integrate as much peer-to-peer collaboration as possible. Our position is that the more modalities and **well-mapped, congruent afferent** sensori-motor activations that are recruited during the encoding of the information, then the crisper and more stable the knowledge representations should be in schematic storage. Watching others master the correct gesture and content will be a learning experience as well, however, the knowledge gained by observation will not be as durable as knowledge gained by action. Recent research supports that content learned in a high embodied condition (versus a low embodied, observational condition) was remembered better on a one-week followup test (Johnson-Glenberg, Megowan, Glenberg, Birchfield & Savio-Ramos, in preparation).

From the designer's perspective, creating a learning module with the highest degree of embodiment means that the module should encourage the student to physically activate a large quantity of sensori-motor neurons in a manner that is congruent to the content being learned. For example, if a student is learning about gears an rotation then a "push" gesture would not be congruent to the task, we suggest designing in a circular motion with the hand to simulate the direction of turn. When the velocity of the rotation, maps to the velocity of the visual graphic, we would consider this to be a highly embodied learning experience. The peer-to-peer collaboration that emerges from immersive, open platform learning is very different from what is seen in desktop learning situations, where students are often focused on their own screens. In addition, these platforms are ripe with observational learning opportunities and these should be thoughtfully and explicitly designed into the lessons.

After years of study, our lab has seen consistent, significant gains in learning when students are randomly assigned to the embodied mixed reality condition (see www.SMALLablearning.com/research). There are two hypothesized reasons for these learning gains: embodiment and collaboration. Due to space constraints, we only describe two of our newer scenarios without final results and recommend the reader visit either one of our two websites: www.smallablearning.com or the EGL group at www.lsi.asu.edu

Game 1: Feed Yer Alien
Feed yer Alien is a nutrition and exergame that has been designed around three primary goals: 1) instruction on optimal food choices, 2) exposure to the new "My Plate" food icon, and 3) sustained moderate physical activity. *Feed yer Alien* is most appropriate for students in 3rd through 8th grade, but it is also relevant for adults. The game begins with the narrative of the player (you) finding a lost and hungry alien under your bed. You both can't communicate, but via trial and error you figure out what makes the alien feel healthier. Immediate sonic and visual feedback help you deduce healthy from unhealthy food choices. Coincidentally, the alien's body functions similarly to a human's. Below is a screen capture of what is projected onto the 15 X 15 floor space. At the center is the dynamic "my plate" icon which has recently replaced the food pyramid (www.myplate.gov).

Two players are active in the game space at one time. One is the selector and the other is the transporter. A forced choice task is shown in the top right corner. Pairs of food items appear on the top of the play space, the selector hovers the motion tracking wand over an item and on the left of the space the nutrients in that item begin to glow. We highlight three nutrients (protein, carbohydrates and fatty acids) and two 'optimizers' (fiber and vitamins/minerals). Via collaborative discussion with the "transporter", who is standing near the nutrients, the team decides which of the two items is more nutritious. The selector picks the virtual item up, in this case the fresh blueberries, and with the wand brings it to the Alien's mouth. Now, it is the job of the transporter to select the glowing nutrients at the

top of the play space and actually "run" them down to the tissue at the bottom of the space in a timely fashion – if this nutrient transport happens too slowly the entire game will begin to dim. If the improper food choice is made (e.g., selecting ice cream with whip cream vs. frozen yogurt with strawberries) then the Alien begins to change color; his antennae and ears begin to droop. In this way, students get immediate feedback on which choices are better. After mastering several cycles at the food choice level, students move on to the portioning level. At the end of what is a five level sequence, the Alien reveals the "secrets of the universe" to the two active students in a manner that only they can see. We are analyzing results now on a study completed in May, 2012.

Method. Over a two hour time period, 24 4th graders played the Alien Heath Game. Pretest and posttests were administered.

Measures. Two separate instruments were administered. *1) Food Choice Test* - A 13 pair forced-choice food item paper and pencil test has been created and piloted. 2) *Build a Lunch Task* – This experimenter-designed task assesses students' food choices as they build a lunch from 21 realistic plastic food replicas. The items ranged from very healthy (grilled skinless chicken breast) to very unhealthy (chocolate donut).

Game 2: HALY - Multi-modal Sensing System for Stress Reduction in Yoga

Healing Arts Lab for Yoga (HALY). The first module created by *HALY* is an immersive visual and sonic landscape designed for community yoga classes aimed at reducing stress. The current implementation, which focuses on color only, is designed to allow the instructor to control the mood of and the color that is saturating a classroom while being thoroughly active and engaged in the teaching. The instructor is able to wear a comfortable glove with a Bluetooth *mudra sensor* in the fingertip that senses pressure and changes projected colors accordingly. The fingertip pressure is mapped to colors based on intensity. Thus, low pressure correlates with "cool" colors (blue, indigo, violet), and high pressure correlates with "warmer" colors (red, orange, yellow). Colors are projected into the environment by a downward facing projector. Color can have a calming effect on people (Madden, Hewett, & Roth, 2000).

The System and Color Therapy Background. HALY consists of a custom-designed glove that utilizes Bluetooth, a force sensitive resistor, a Lilypad arduino, and is powered by 3.3 Volts through a AAA battery in a Lilypad battery circuit. The Bluetooth sensor transmits the data to a Max / MSP patch which maps the sensor data to color visuals. The colors visuals are projected through a downward facing projector and feel immersive. The working hypothesis is that by combining immersive color therapy with a yoga environment, participants will report feeling calmer than when they are in a simple yoga-only environment.

An Embodied Taxonomy for Serious Games

Our lab is creating a taxonomy to partition embodied, "kinesthetic" learning environments into meaningful categories so that falsifiable hypotheses can be framed. The education sector is now receiving the opening salvos from marketing materials claiming that virtually every tap on a Tablet screen is "highly embodied". We would do well to pause and reflect on what it means for gestures to be embodied in a meaningful way that maps to the congruency of the content being learned. What affordances are necessary components in the embodied learning equation? How should the varying constellations (and magnitudes) of these learning affordances be ranked? To this end, Johnson-Glenberg (et al., submitted) posit three necessary components: 1) amount of motoric engagement, 2) gestural relevancy or congruency–how well-mapped the evoked gesture is to the content being learned, and 3) perception of immersion. These components can range from low to high; however, a useful matrix might be one that contained four degrees of embodiment. The 4th degree would be considered the highest.

4th degree= Includes locomotion which results in a high degree of motoric engagement; gestures designed to map to content learned; learner perceives environment as very immersive (Example – systems described in this symposium that include locomotion.).
3rd degree = No sustained locomotion, but large amounts of sensori-motor activation are present while stationary; some amount of gestural relevancy; learner perceives environment as immersive (Example - VR goggles, generative content on Interactive Whiteboards).

2nd degree = Learner is generally seated, upper body movement; interfaces should be highly interactive; with smaller display size of a computer monitor learner does not perceive as highly immersive (Example- constructive desktop simulations).

1st degree = Learner is generally seated, some upper body movement; primarily observes video/simulations on monitor (Example – view video on screen).

Our claim is that for a learning module to be considered *embodied to the highest degree* it should activate a large number afferent neurons in the learner's motor system – akin to what happens during Self Performing Tasks (Engelkamp, 2001) in the psychology literature. This combination of body-based muscle engagement and brain-based mirror neuron activation results in 4th degree learning. Removing the body-based (kinesthetic) component, will still result in learning; however, it may not be as durable as the learning supported by both forms of encoding.

Presentation 2: Outbreak! An Embodied, Immersive and Collaborative STEM Learning Environment

Tatyana Koziupa, Mina C. Johnson-Glenberg, and David Birchfield

Outbreak! is a STEM (Science, Technology, Engineering and Math) game designed for the Situated Multimedia Arts Learning Lab *(SMALLab)* multi-modal environment. Multi-modal means that the learners use multiple senses (seeing, hearing, kinesthetic) to encode the information and integrate immediate feedback. Our lab co-designs all content with K-12 teachers and aims to systematically include opportunities for peer-to-peer or whole class collaboration in the scenarios because research supports the many positive effects of collaboration and cooperative learning in the classroom. (*SMALLab* is well situated for teaching about the complexity of human diseases because it is learner-centered, inquiry-based, and contains embodied learning experiences designed to better align real world experiences with abstract representations and conceptual models.

Design and Development of the Disease Transmission Game

Outbreak! was designed with a high-school science teacher to address common misconceptions of disease transmission, including the difference between bacterial infections and viruses, the difference between antibiotics and vaccines, the meaning of antibiotic resistance, the difference between symptomatic and asymptomatic carriers, and the concept of limited resources. The scenario was implemented using design principles outlined in Birchfield et al. (2010b). We insured that it was collaborative, embodied and wrapped in an inquiry-based social game. Avatars were created by the students at a free website before the study began and then were imported into the game template. During each run, infection levels were randomly assigned to each avatar. Once the students successfully identified how the disease was transmitted – for example, via bacteria or virus - a new complexity was added to the system, e.g., asymptomatic carriers. In this way it leveled in complexity over a three day time period.

Mechanics. The health disc surrounding each avatar decremented with time and this motivated the students to retrieve more water or medicine in the central playing area. Unfortunately, the central area was also where they could get sick. Students needed to first deduce the method of transmission and then work through whether the disease was due to a bacterial or viral infection. The timing and efficacy of the medicine was crucial for figuring out this distinction. The lesson lasted for three days with increasing levels of complexity culminating in the asymptomatic carrier level where students needed to figure out who was the carrier without any visual cues attached to the avatar (i.e., which avatar was in the space at t-1 now that avatar X is sick?)

Methods. The Outbreak! study was run on a large urban high school with 56 students. The study was based on a six-day waitlist design. Three invariant (pre-, mid-, and post-) tests were administered to three classes, which were randomly assigned to group. Group 1 received *SMALLab* instruction then regular instruction (same teacher and same content); Group 2 received regular instruction then *SMALLab* instruction. A mid-test was given halfway through and then intervention switched. When students were in the *SMALLab* condition the Effect Size (ES) was always over .50 – when they were in the regular instruction condition the ES was below that – either .32 or .09 respectively.

Results & Discussion

By Midtest the groups differed significantly, with greater gains favoring the *SMALLab* learning experience as compared to regular classroom instruction. A *t* test significantly favored the group that

received *SMALLab first*. We believe that the collaborative embodied experience accounted for this gain.

Conclusions & Future Directions
This scenario was designed to foster systems thinking skills. The *SMALLab* mixed reality environment is an example of a highly innovative learning space for developing creative, non-linear, and operational thinking skills that are necessary for developing a systems thinking approach to problem-solving. OUTBREAK! allows the students to follow the inquiry-based learning model, and proceed through the scientific method to test their hypotheses in a supportive, yet rapidly evolving time frame that encourages multiple hypotheses to be posited, refuted or supported. It is highly collaborative. There were times when half the class was shouting out recommendations about whom to save and whom to "quarantine". (To see video go to: www.smallablearning.com scenario: disease transmission).

Presentation 3: Embodied Learning in a Mixed Reality Game through Metaphor-Based Interactions- Meteor
Amy Bolling[1], Arjun Nagendran[2], and Robb Lindgren[1]

Mixed reality environments are those that merge the real and the virtual, integrating real world environments with virtual elements and vice versa (Milgram & Colquhoun, 1999). The potential of using mixed reality to create new learning experiences and educational opportunities has been frequently cited (Chang, Lee, Wang, & Chen, 2010; Hughes, Stapleton, Hughes, & Smith, 2005; Kirkley & Kirkley, 2005; Pan, Cheok, Yang, Zhu, & Shi, 2006). Learning through physical interactions with MR has been referred to as type of *embodied learning* (Birchfield & Johnson-Glenberg, 2010). Recent advances in mixed reality technology permit the creation of immersive environments capable of seamlessly integrating a learner's real world movement and activity with digital representations. Relatively inexpensive infrared and laser-based motion tracking systems make it possible for these environments to be highly responsive and interactive without the need for users to wear heavy and intrusive technologies (e.g., Snibbe & Raffle, 2009); this means that learners can freely explore digital spaces with natural physicality. Given these affordances, we have created a mixed reality environment that aims explicitly to support *body-based metaphors* in which participant learners interact with the environment as though their body was a part of the representational system.

Mixed Reality in Informal Science Education
The mixed reality game, "MEteor," is designed as an interactive physics exhibit that can be installed in a science center. According to the recent report simulations and games may be particularly effective at increasing excitement in the subject matter and motivation for continued learning (Honey & Hilton, 2011). This makes the use of simulations and games using mixed reality technologies in large exploratory spaces especially applicable to informal environments such as science centers. Indeed, many science centers have begun to embrace these technologies in recent years, although rigorous research on the specific effects of these experiences on visitor learning and engagement has been sparse. We seek to build upon this work to show specific affordances of mixed reality environments for supporting cognitive processes.

In the MEteor game we are employing *functional metaphors* to help learners construct an understanding of planetary physics. The metaphor "learner as asteroid" is embodied in the sense that we are asking participants to enact the metaphor using their own bodies and "functional" in the sense that through this behavior they draw similarities between the way physics functions and the functions they are performing. Through this functional-embodied metaphor, the subject's body becomes a component (an asteroid) in a complex system (planetary astronomy). Through their own physical actions thesubject learns about the behavior and important relationships that govern the system.

Project Design
The goal of this educational game is to facilitate science learning through whole-body interactions. The game was designed for middle school-aged children to explore the world of planetary physics through their interactions with functional metaphors. We are currently conducting studies on the game at our lab and the game will shortly be installed at the Museum of Science and Industry (MOSI) in Tampa, FL. The science concepts explored through this serious game are Newton's laws of motion and Kepler's laws of planetary motion.

Five levels of the game were designed to lead the student through the increasingly complex laws of motion. In this immersive mixed reality environment, there is a zone on the floor in which the student maintains control over the motion of the asteroid (a "launch" zone, followed by a zone in which the asteroid is controlled entirely by the laws of physics. In this second zone, the student must do his/her best to keep up with the motion of the asteroid and is scored according to how well s/he predicts and follows the path of the asteroid. Whether or not the students actually hit the target is secondary to their ability to predict its motion and move accordingly. Thus, the feedback that the participant receives through graphs and imagery on a large wall or floor projection is focused on the distance between the student and the asteroid over time. The student is scored on each trial. In the second and third level of the game the student must hit the same target which now lies on the opposite side of a large planet and a smaller planet respectively. In order to hit the target the student must get a sense for how the presence of this planet affects the trajectory of the asteroid.

Learning Research

This paradigm for enacting functional metaphors in a mixed reality environment is already showing benefits for learning. In preliminary studies described in Lindgren and Moshell (2011), we found that participants who used MEteor were more likely to include dynamic elements (arrows, etc.) in their astronomy drawings compared to participants who used a desktop computer version, indeed 52% of participants in the whole-body condition created sketches that represented movement compared to 41% of participants in the desktop condition. MEteor participants were additionally less likely to include "surface features" (graphical elements that were in the simulation but not really important to the physics being learned) in their drawings. Having participants make drawings of the simulations proved to be a highly informative measure of a participant's remembered experience. Other measures include picture-based surveys of science self-efficacy and an analysis of a learner's gestures while playing the game. We believe this new approach to informal science education is already showing great promise. We know that games that incorporate physicality into their scheme of interactions can be engaging. The current work indicates that these games can help develop important forms of conceptual understanding as well.

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