You're It! Body, Action, and Object in STEM Learning

Dor Abrahamson (Chair), UC Berkeley, 4649 Tolman Hall, Berkeley, CA 94720-1670, dor@berkeley.edu
Carmen J. Petrick & H. Taylor Martin, UT Austin, 1 University Station D5700, carmenpetrick@gmail.com
David J. DeLiema, Noel Enyedy, Francis F. Sten, & Darin Hoyer, UC Los Angeles, ddeliema@gmail.com
Mina C. Johnson–Glenberg, David Birchfield, Tatyana Koziupa, Caroline Savio-Ramos, & Julie Cruse,
School of Arts, Media + Engineering, Arizona State U., Tempe, AZ, Mina.Johnson@asu.edu
Robb Lindgren, Anthony Aakre, & J. Michael Moshell, University of Central Florida, Robb.Lindgren@ucf.edu
Cameron L. Fadjo & John B. Black, Teachers College, Columbia, 525 W. 120th St., NY, clf2110@columbia.edu
Mike Eisenberg (Discussant), U. Colorado, Campus Box 430, Michael.Eisenberg@colorado.edu

Abstract: In this special double symposium, sixteen established and emerging scholars from seven US universities, who share theoretical perspectives of grounded cognition, empirical contexts of design for STEM content domains, and analytic attention to nuances of multimodal expression, all gather to explore synergy and coherence across their diverging research questions, methodologies, and conclusions in light of the conference theme "Future of Learning." Jointly we ask, What are the relations among embodiment, action, artifacts, and discourse in the development of mathematical, scientific, engineering, or computer-sciences concepts? The session offers emerging answers as well as implications for theory and practice.

> THERE was a child went forth every day;
> And the first object he look'd upon, that object he became;
> And that object became part of him for the day, or a certain part of the day,
> or for many years, or stretching cycles of years. (Walt Whitman)

Introduction: "You're It!" Is More Than a Tagline

"You're it!", so mundane a playground exclamation, appears to capture much more of human experience than a game of tag. To each of us—16 established and emerging scholars from seven different universities across the US—"You're it!" bears in profound and empirically substantiated ways on relations among action, embodiment, artifacts, reasoning, and discourse, as these relations pertain to developing competence in some STEM domain (Science, Technology, Engineering, Mathematics). Our distinct yet teaming ideas, we sense, should be gathered and shared among us and the larger learning-sciences community, because apparently these ideas collectively hone and point toward what might be the theoretical core and pedagogical promise of the embodiment approach. In this symposium, we attempt to shed light on the nature and dynamics of enactment, integration, and signification as naturalistic learning phases that can be recruited via pedagogical design for content instruction.

Each study interprets cases of mediated interactions designed and facilitated with the objective of fostering knowledge (which we conceptualize and pin down from varying epistemological perspectives as professional perception, insight, models, skills, etc). Moreover, each presentation provides rich qualitative analyses of paradigmatic moments, in which study participants' physical action—whether with, upon, or about objects that are either material, virtual, or imaginary—contributes to individual microgenesis of target subject matter. Yet more specifically, we are all interested in elaborating from a grounded-cognition perspective theoretical models pertaining to manipulation—whether actual, vicarious, or simulated—and how these operations contribute to learning.

All the data discussed in this symposium were collected in instructional situations, writ large. Turning to instructional practice, we are also interested in determining and characterizing any unique pedagogical affordances of particular technology and interaction strategies vis-à-vis student cognition of focal content. Thus, in accord with the ICLS 2012 "The Future of Learning" theme, this symposium attempts to ground next-generation interaction design in established tenets of learning sciences theory. Our discussant, Mike Eisenberg, brings to this symposium his renowned expertise in cognitive science, computer science, mathematics, engineering, and integrated multimedia design for STEM content learning.

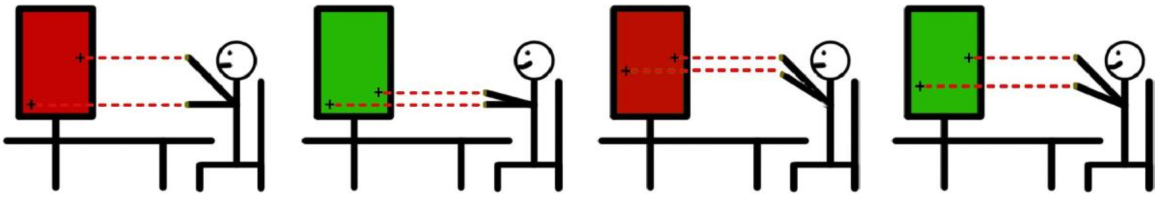
In writing our individual sections, we chose to use a common format, so as to highlight our similarities and suggest our synergies. The sections present the proposed papers in their intended order of presentation. During the 120 min. session, these six individual papers (6 x 15 min.) will be followed by comments from our discussant (20 min.), and then we will engage in a general discussion with the audience (10 min.). To varying degrees, presenters will bring software, media, and artifacts from their respective research studies that will enhance post-symposium informal follow-up conversations with interested members of the audience.

You Made It! From Action to Object in Guided Embodied Interaction Design

Dor Abrahamson, Dragan Trninic, and José F. Gutiérrez, University of California at Berkeley

> "Object" is supposed to mean....something that is either internally or externally present in a certain situation. Thus, not only external *things* like....wood blocks, or *signs* and *persons*, are objects, but it is also possible that a certain form of knowledge or a certain cognitive ability is the "object." (Hoffmann, 2007, p. 189, original italics)

What role might instructors play in scaffolding students' generalizations from embodied interaction? Twenty-two Grade 4-6 students (ages 9-11) participated, either individually or in pairs, in a task-based, semi-structured, tutorial clinical interview. The intervention's objective was to gather empirical data for a design-based research study investigating the emergence of conceptual knowledge from physical activity. Under the researcher's guidance, participants engaged in an embodied-interaction problem-solving activity. Their task was to make a computer screen green by remote-controlling two virtual objects, one hand each. Unknown to them, the screen would be green only when their hands were at particular heights above the desk, relative to each other (see Figure 1). In Abrahamson, Trninic, Gutiérrez, Huth, and Lee (2011) we describe the following typical participation trajectory. Students first developed naïve qualitative strategies (e.g., "The higher you go, the bigger the distance"). Next, when we overlaid a virtual Cartesian grid on the screen, they used this mathematical resource to bootstrap an *a*-per-*b* form (e.g., "For every one unit I go up on the left, I got up two on the right"); and when we supplemented numerals, they determined a multiplicative relation (e.g., "The right hand is always double the left hand"). Here we report on a study of the tutor's function in scaffolding these insights.



a. b. c. d.

Figure 1. The Mathematical Imagery Trainer for Proportion (MIT-P) set at a 1:2 ratio, so that the right hand needs to be twice as high along the monitor as the left hand. In an empirically determined schematic interaction sequence, the student: (a) positions hands incorrectly (red feedback); (b) stumbles on a correct position (green); (c) raises hands *maintaining constant distance between* them (red); and (d) corrects position (green), infers rule. Compare 1b and 1d—note the different distances between the cursors.

The following transcription from our empirical data is presented to illustrate the microgenesis of mathematical objects via guided, mediated embodied interaction. In particular, we attend to nuanced language features—sliding uses and substitution of pronouns—as indicators of how a dyad zigzags between embodied actions, relations, and rules, ultimately objectifying referents in a shared perceptuomotor field, all so as to repair "designed" practical and discursive vagueness (Abrahamson et al., 2009; Newman, Griffin, & Cole, 1989; Rowland, 1999). As per Hoffmann's quotation in our motto, indeed our "object" is an externally present thing—an "invisible" distance between two points. This particular phenomenological object is of critical importance to learning via our design: noticing, controlling, and naming it is the first step to articulate a proto-ratio principle.

Dor: So what's the rule? What makes it green? [= scaffolds reflection, requests generalization]
Amira: Having this one [*she indicates her right hand*] be higher [...*she indicates her left hand*].
D: Hn'hn. Ok. So, *any* higher? [= implies a request for more specificity. Note: the grid is on.]
A: ....about three squares higher. [= complies by offering quantitative relational locator]
D: Three squares higher. Ok. So if you bring your hands down... [= launches generalization]
A: I think it's like, if it's up here also... There's like a few spaces where it's.... In some spaces you have to be lower down. [= in some areas on the screen the interval is smaller]
D: Aha. In some spaces you have to be lower down. [= echoes; implies positive valorization]
A: Yeah. Right down here. But then when you go up here, you have to be higher.
D: Ah! Ok, so some spaces you have to be down, but then when you go up there, it has to be... [= echoes, but switches "you" to "it"; elides "higher" to invite another, clearer descriptor]
A: Yeah... A bigger distance. [= offers "distance" as an alternative completion of the assertion, and thus disambiguates that her "higher" had referred to the hands' interval not elevation]
D: A bigger distance. Ok. [= echoes; affirms with explicit positive valorization]
A: Down here you only need about one. ["one" indicates absolute, not relational interval]

D: Ok, so down there <u>you</u> only need about one. [echoes]
A: .... As <u>you</u> keep going up, <u>it</u> has to be more..... Here it's 1, ...2...3...4...5 [infers; applies]

We thus witness how goal-oriented interaction situated in discursive interaction "begets" a mathematical object.

During the presentation, I will screen several samples of video footage, in which tutor–tutee dyads co-construct mathematical referents using available semiotic means of objectification (Radford, 2003), including speech, gesture, gaze, and material–virtual resources. I will interpret those unique moments as culminating brief histories of localized discursive interaction around task-based pedagogical activity.

Learning Mathematics: You're It vs. It's It

Carmen J. Petrick and H. Taylor Martin, University of Texas at Austin

> Children's play is everywhere permeated by mimetic modes of behavior, and its realm is by no means limited to what one person can imitate in another. The child plays at being not only a shopkeeper or teacher but also as windmill and a train. Of what use to him is this schooling of his mimetic faculty? (Benjamin, 1986, p. 333)

This presentation reports on part of a larger study comparing students learning geometry through either embodied or observational activities. There is evidence that embodying concepts is beneficial to learners (Abrahamson, 2004; Fadjo, Lu, & Black, 2009; Roth, 2001); yet, little is known about the differences in the learning process between students who physically enact concepts and students who do not. This study compares how high school students remembered an activity in which they explored the concept of ratio by either "being it" or "watching it." By "being it," we mean experiencing oneself as the mathematical object. In contrast, we refer to "watching it" as observing a mathematical object as being remote and separate from oneself.

We use a theoretical framework of embodied cognition as we try to understand how being in a body and interacting with objects in the world can influence how students make meaning of mathematics (Anderson, 2003; Barsalou, 2008; Wilson, 2002). Being able to "get inside" a problem can be a helpful strategy for students learning mathematics (Wright, 2001). Embodiment is one way to help students do that (Noble, Nemirovsky, Wright, & Cornelia, 2001; Petrick, Berland, & Martin, 2011; Wilensky & Reisman, 2006). When a student becomes "it," we hypothesize that he or she will have a very different kind of experience than a student who detachedly watches "it," because embodiment promotes connections between physical actions and mathematics in a way that observing does not. In this study we examined students' written responses to a survey asking them to write what they remembered about a learning activity, and we compared two groups of students: those who learned through embodiment (n = 69) and those who learned by observing (n = 59). We predicted that students in the embodied condition would remember more about the activity as a whole. Also, we predicted that students in the embodied condition would be more likely to write their responses in a first-person narrative, thus showing that they had realized *they* were *it*.

In the larger study, fourteen classes of high school geometry students followed a two-week curriculum on similarity. Four teachers participated in the study, and half of each teachers' classes were randomly assigned to either the embodied or observer condition. Students in the embodied condition participated in eight activities designed to promote direct embodiment of mathematical ideas, such as ratio and similar triangles. In these activities, the students became "it" by physically enacting the concepts. Students in the observer condition participated in eight activities that were very similar to the embodied condition, except these students observed or drew pictures of abstract symbols enacting the concepts rather than embodying them. Unit pre- and post-tests showed that students in the embodied condition had greater learning gains than students in the observer condition, and that these differences were found on the conceptual items of the test but not the procedural items (see Petrick & Martin, 2011).

To look closer at how the students experienced the different types of activities, we administered a survey at the end of the unit asking students to write down everything they remembered about each of the eight activities. We have chosen to focus on the first activity of the unit, called Make the Screen Green, for this presentation. In the embodied condition, students interacted with a version of the Mathematical Imagery Trainer ("MIT"; Abrahamson & Howison, 2010), in which they used Wii remotes to control the heights of two blocks on a screen (see Figure 1, below). Students took turns moving the remotes to help them find the hidden rule that turned the screen from red to green, and every few minutes the teacher would ask students to use their hands to simulate the positions of the blocks that they thought would make the screen green. As they did this, each student's partner would give feedback. Students in the observer condition did not manipulate the blocks or simulate the movements of the blocks with their hands. Instead, they watched a video showing the same blocks and screen that students in the embodied condition saw. Similarly, the screen would turn green whenever the ratio of the heights of the blocks was 2:1. Yet this video was a recording of other students' interactions with the

MIT from an earlier pilot. Here, too, every few minutes the teacher would ask students to describe to their partner what made they thought made the screen turn green, and each student's partner would offer feedback.

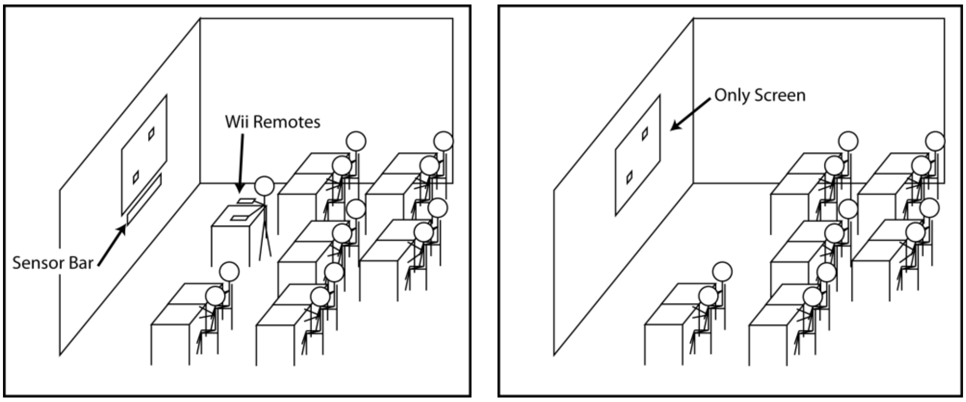


Figure 1. Classroom setup for "Make the Screen Green": embodied condition (left) observer condition (right).

After analyzing what all students wrote on their survey at the end of the unit, we found that students in the embodied condition wrote significantly more words overall in their response than students in the observer condition. Upon looking more deeply, we found that the embodied condition wrote significantly more mathematical details (e.g., mentioning a two-to-one relationship) than students in the observer condition, and they also wrote significantly more non-mathematical details (e.g., names of partners). In addition, we found that students in the embodied condition were significantly more likely to adopt first-person narratives, while students in the observer condition were significantly more likely to write from a third-person narrative. These differences appear even though there were no significant differences between conditions in student learning on procedural items on the unit pre- and post-tests. During the presentation, we will discuss further details about the two activities, information about the analyses, and implications of these results for the theory and practice of mathematics education.

Learning Science by Being You, Being It, Being Both

David J. DeLiema, Noel Enyedy, Francis F. Steen, and Darin Hoyer, U. of California at Los Angeles

> When I observed phenomena in the laboratory that I did not understand, I would also ask questions as if interrogating myself: "Why would I do that if I were a virus or a cancer cell, or the immune system. (Salk, 1983, p. 7)

This presentation reports on findings from an ongoing research project investigating the role of physical action, particularly gesture, in learning scientific content. It has been theorized that learning science involves the construction of mental models (cf. Frederiksen, White, & Gutwill, 1999; Gentner & Stevens, 1983; Johnson-Laird, 1983). The objective of my project is to revisit and potentially qualify these theories from the perspective of the rising paradigm of grounded cognition (Barsalou, 2010). The current study, by analyzing students' gestures during the incipient moments of mental model construction, is a first step toward that goal.

According to classical computationalism (Gentner & Stevens, 1983), modeling transpires entirely inside the head (Greca & Moreira, 2000). Yet this classical theory, which conceptualizes models as formed out of propositional mental symbols, bears the fundamental methodological disadvantage that these cognitive constructs cannot be seen or measured, such as when students study content (Rouse & Morris, 1986, p. 1). Regardless of whether or not these theories obtain, one methodological means of monitoring learning is asking people to represent their emerging understandings in speech and diagrams (Coll & Treagust, 2001; Harrison & Treagust, 1996; Niedderer & Goldberg, 1996). The present study looks to productions in another semiotic modality, hand gestures, as "physically instantiated mental models" (Schwartz & Black, 1996, p. 464; see also Clement & Steinberg, 2002; Crowder, 1996). A methodological advantage of studying gestures, in this respect, is their relatively unmediated presentation of thought process, as compared to verbally or diagrammatically instantiated mental models.

For the current study, I selected the conceptual content of "packet switching," the historical technological innovation that gave rise to the Internet. Study participants with no prior knowledge of packet switching were asked to perform *interpretive gestures* at the same time as they listened to verbal statements about this system. The term interpretive gesture refers to the student's attempt to comprehend and then gesturally model the words of the conversation partner, as the discourse unfolds. Next, I had participants discuss packet switching more naturally (i.e. spontaneously using co-speech gestures). As I now elaborate, this nonroutine procedure offers a unique window onto the microevolution of a mental model. The following builds on intensive analysis of a case study consisting of a single participant (Cynthia [pseudonym], a college student).

The analysis builds on the thesis that students reasoning about STEM phenomena naturally enact both Observer ViewPoints (O-VPT, seeing the phenomenon from outside) and first-person, anthropomorphized Character ViewPoints (C-VPT, "being" the phenomenon; see Nemirovsky & Monk, 2000; Ochs et al., 1996; Wilensky & Reisman, 2006). Indeed, the student in the present study routinely alternated between O-VPT *of* components and C-VPT *as* components. In several instances, the student coordinated static O-VPT representations of the component shape (i.e. box-like) with dynamical C-VPT representations of its actions (i.e. grasping or inscribing). (In the following example, the researcher's speech is in inscribed in roman type, and *Cynthia's gestures, which follow each of the researcher's speech turns, are in italics.*)

> Each packet [*left hand forms horizontal box shape and remains in place*] grabs a few small pieces of the email message [*right hand reaches out, plucks an imaginary small object from the air* (see Figure 1] and stores those pieces inside itself [*places the object "inside" the left hand—repeats three times*].

Figure 1. Cynthia's left hand *is* a packet; her right hand operates *as* a packet *on* itself.

Cynthia's left hand established narrative context by instantiating an O-VPT packet, even as the right hand, representing a "hand" of the same packet, acted upon it as a C-VPT element. By this token, "You're it" means importing naturalistic interaction schemas into the inquiry process by literally being the phenomenon in question. Gestures, by concretizing *your* view when you dive in to be it, and concretizing *its* view when you dive out to observe it, support the dynamic coordination between the You and It viewpoints by blending into a single model traces of their respective allocentric and egocentric experiences. These same viewpoints for depictions of system events tended to reappear in Cynthia's co-speech gestures during her later retelling of packet switching.

During my presentation, I will show video clips of the learning interaction and provide moment-to-moment analyses of how Cynthia's gestures build multiviewpoint models, establish context around action, and produce evolving representations, and I offer implications for the design of virtual STEM environments.

Seeing It versus Doing It: Lessons from Mixed Reality STEM Education

Mina Johnson–Glenberg, David Birchfield, Tatyana Koziupa, Caroline Savio-Ramos, and Julie Cruse
School of Arts, Media + Engineering, and the Learning Sciences Institute, Arizona State University

> Watching a child makes it obvious that the development of his mind comes about through his movements…. Mind and movement are parts of the same entity. (Maria Montessori, 1967)

Mixed-reality embodied learning platforms are coming of age. We will present several studies that have demonstrated increased learning when students are randomly assigned to embodied, mixed-reality (MR) environments compared to learning in regular instruction environments, where teacher and content are held constant. The SMALLab (Situated Multimedia Arts Learning Lab) and Serious Games for Embodied Learning groups at ASU create and research content for K-12 education that is embedded in kinesthetic platforms. (See www.smallablearning.com for videos.) We explore the boundaries of environments that use the body as an interface for learning. The two most common platforms are rigid body motion- and skeletal-tracking cameras (e.g., *Kinect*). We co-design all lessons with classroom teachers to create content that engages the major sense modalities (visual, auditory, and kinesthetic). *SMALLab* uses 12 infrared motion-tracking cameras to send to a computer information about where a student is in a 15 X 15 ft. floor-projected environment. Students step into the active space and hold a “wand” (a trackable object) that allows the physical body to function as a 3D cursor in the interactive space. Figure 1 shows two students using wands to manipulate elements in a chemistry lesson.

Figure 1. Two students adding molecules into a virtual flask in a chemistry titration scenario.

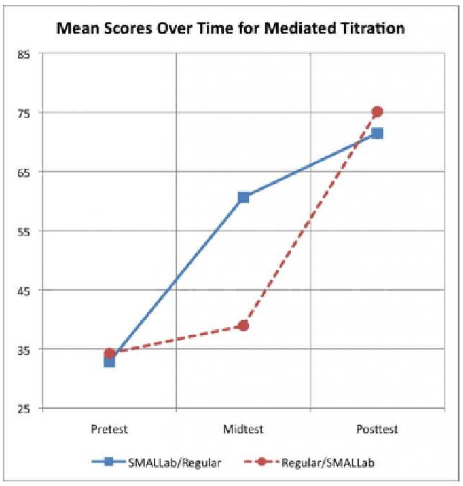


Figure 2. Comparative mean scores over time for chemistry scenario.

With turn-taking, entire classrooms with 30 students are able to physically experience a learning scenario within a typical class period. We contend that the more modalities (sensorimotor systems) are activated during the encoding of information, the crisper and more stable the knowledge 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 should be a powerful teaching aid. Yet, it is not trivial to create “congruent” gestures that map to the lesson that is to be learned (we use *congruent* the way Segal, Black, Tversky, 2010, do). To this end, we will also present some design guidelines for creating meaningful embodied content and how to think about action as a method for deeper encoding.

Several studies have been published supporting significantly larger learning gains when students are active in *SMALLab* versus regular instruction (Birchfield & Johnson–Glenberg, 2010; Johnson-Glenberg et al., 2009, Tolentino et al., 2009). We hypothesize the primary drivers for the learning changes are embodiment, collaboration, and novelty. In addition, the gains also may be mediated by increased peer-to-peer language use and gameplay. Results from several experiments will be presented, including the titration chemistry scenario. Our studies typically use a waitlist design and three invariant tests. Figure 2 shows that significant gains are observed each time the classes are assigned to the *SMALLab* condition. We have analyzed results from 200 students in a study designed to address the question of *watching it versus being it*. We label these two conditions as low vs. high embodiment. The two embodied levels are crossed with three learning platforms: *SMALLab*, an interactive whiteboard (IWB), or a desktop-and-mouse condition. Psychology undergraduates experience a one-hour lesson on Centripetal Force.

The research has led to several design principles intended to frame the realization of embodied learning experiences in computer-mediated environments (Birchfield, Johnson–Glenberg, Megowan–Romanowicz, Savvides, & Uysal, 2010). Specifically:

- *Direct Impact*: Learners’ physical actions should have a direct, causal impact in the simulated environment;
- *Map to Function*: A learner’s gesture should closely align with its function and role in the simulated environment (e.g., physical and simulated throwing gestures should align);
- *Human Scale*: Computer interfaces should support movement on a human scale (e.g., degrees of freedom, size, and speed of a gesture);
- *Socio-Cultural Meaning*: The communicative aspects of human presence and gesture should be accounted for (e.g., the cultural meaning of a gesture, the information conveyed by a gesture needs to be addressed).

You're the Asteroid! Body-Based Metaphors in a Mixed Reality Simulation of Planetary Astronomy

Robb Lindgren, Anthony Aakre, and J. Michael Moshell, University of Central Florida

> The brain's sensorimotor representations of space "gain their coherence not by their subservience to some over-arching, mathematical definition of space but with respect to a repertoire of movement. (Arbib, 1991, p. 379, as quoted by Hagendoorn, 2012)

In this paper we describe a specific approach to generating embodied learning, where users are embedded within a simulation and given the opportunity to learn the important relationships from the inside. A number of recent reports have highlighted the benefits of informal, simulation-based learning experience for science education (Bell et al., 2009; Honey & Hilton, 2011), but there has been fairly little specificity about how the interactions one has with these simulations affect learning. Building upon recent work where mixed reality (MR) environments (the merging of physical and virtual elements in interactive spaces) have been shown to have great potential for facilitating learning (e.g., Birchfield & Johnson-Glenberg, 2010; Hughes, Stapleton, Hughes, & Smith, 2005; Kirkley & Kirkley, 2005), we have developed an interaction approach we call "body-based metaphors." Unlike the relational metaphors that drive certain kinds of knowledge construction described by Gentner (1988), body-based metaphors are *functional metaphors* where the source domain (S) functions (or is made to function) like the target domain (T). In the MR environment we have developed, learners enact functional metaphors by using their bodies to act out part of a simulation of planetary astronomy (see Figure 1). We believe that these body-based metaphors are particularly effective for young learners who may struggle with the structure mapping process associated with relational metaphors.

Figure 1. A middle school student uses their body to put an asteroid into orbit.

The learning goal for this project is to develop intuitions about physics concepts related to planetary movement (orbits, gravity, etc.). Philosophers have argued that body activity serves as the basis of conceptual understanding (Gallagher, 2005; Johnson, 1987), and this may be especially true of understanding spatial relationships. The use of body activity to teach physics concepts has been met with mixed success previously, likely because Earth does not provide a "pure" environment for examining elements such as force. With MR, however, it is possible both to isolate these elements and connect bodily movement with the abstract representations (graphs, vector diagrams, etc.) that are typically used to convey knowledge of physics.

We will describe data from research we have conducted to investigate whether the body-based metaphor approach of interacting with digital simulations has advantages over the traditional mouse-and-keyboard interface. To conduct this research we created a simulation game we call MEteor that can be run on both a 30-foot-by-10-foot interactive floor space and standard desktop computer. Participants work through a series of game levels that require a basic understanding of Newton's and Kepler's laws (e.g., hitting a target on the opposite side of a large planet). A separate display shows the participant their movement within a graph, allowing them to assess their predictions compared to the actual movement of objects as dictated by the laws of physics. We are applying a number of traditional metrics of learning (pre- and post- knowledge questions, questionnaires about science efficacy), but we are also utilizing a number of alternative measures to probe for effects that may be more commensurate with the modality of learning in this simulation. For example, in our preliminary research we found that participants' sketches of the simulation included more dynamic elements (arrows showing movement, etc.) and less surface features (textures, background objects) when using the MR simulation compared to the desktop simulation.

A primary focus of this research is whether or not we can develop effective measures that specifically target embodied learning. We are interested, first, whether or not a learner's experience and level of comfort with physical and "embodied activities" (e.g., sports, dance, 4H, girl scouts, etc.) predispose them to success with the type of interactive learning intervention we have developed. A recent paper on dance and spatial cognition provides a good example of how experiencing different and more types of movements creates a greater repertoire for understanding (Hagendoorn, 2012). To this end we are using a pre-questionnaire that surveys the participant's experience in various physical activities and the types of things they do with their bodies to aid their thinking. A second measure we use is recording the degree to which a participant's movements are consistent with the normative trajectories of simulation elements, and how these patterns of movement change over time. We hope to see, for example, that participants using the immersive MR simulation quickly adapt their movements to match how things actually move in space (e.g., slowing down when an orbiting asteroid is far away from the planet and speeding up when closer). Finally we observe the quantity and kind of gestures participants use both in the simulation and outside of it when explaining their reasoning about physics. Previous research has shown that gestures have a significant impact on cognition (Goldin-Meadow, 2003; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001), and we are interested in whether a greater propensity to gesture is related to the other knowledge and performance measures being applied. We are using motion tracking to quantify the degree that participants are gesturing in the simulation and using video protocols to analyze gesture in pre- and post-interviews. These varied measures are allowing us to produce a more nuanced description and evaluation of embodied learning generally and body-based metaphors specifically.

You're In the Game: Direct Embodiment and Computational Artifact Construction

Cameron L. Fadjo and John B. Black, Teachers College, Columbia University

> Virtual characters have virtual minds and virtual bodies. They become the player's surrogate mind and body. (Gee, 2010, p. 258)

This presentation reports on findings from a field-based study investigating the learning of abstract computer science concepts and skills through physical action. Recent research in embodied and grounded cognition has examined the roles action, perception, and environment play in the teaching and learning of abstract concepts in mathematics (Abrahamson, 2010), science (Barab et al., 2007; Chan & Black, 2006), dance (Grafton & Cross, 2008), drama (Noice & Noice, 2006), and robotics (Lu, Kang, Huang, & Black, 2011; Petrick et al., 2011). The objective of this study is to examine if physical, or Direct (Fadjo & Black, 2011) and Imagined Embodiment (Fadjo & Black, 2011) during pedagogical activities improves the learning of abstract concepts in computer science. In particular, we are interested in examining if the embodiment of pre-defined dialogue-based scripts during classroom instruction improves the development of certain Computational Thinking skills and concept knowledge (Resnick & Brennan, 2011; Wing, 2006) during the construction of a computational artifact. This work is a first step toward defining a grounded embodied epistemology of pedagogy.

Embodied (Glenberg, 2010) and grounded (Barsalou, 2010) perspectives of cognition have emerged over the past thirty years as the traditional Cartesian dualism view of cognition has been challenged (Gibbs, 2006). In particular, the problems of transduction (Barsalou, 1999) and grounding (Harnad, 1990; c.f. Pecher & Zwaan) have led cognitive scientists, cognitive psychologists, and philosophers to question the role the body plays in cognition. Further exploration of these problems has resulted in the emergence of two major developments in support of an 'embodied' cognition (Gibbs, 2006). The first development, dynamical systems theory, emerged from the fields of artificial intelligence and cognitive science as a way to define and explore the complex relationship between mind, body, and environment in cognition (Gibbs, 2006; Robbins & Aydede, 2009). The second development within embodied cognition comes primarily from work in the field of cognitive linguistics that emphasizes the importance of linguistic structures on "human conceptual knowledge, bodily experience, and the communicative functions of discourse" (Gibbs, 2006). Our study examines the development of Computational Thinking through an embodied approach to learning the language of computing. Recent studies by Glenberg and colleagues (2009, 2004) have demonstrated that an embodied approach to reading comprehension through physical and imagined manipulation is highly effective for learning abstract concepts in novel scenarios. This study extends previous work on embodied learning by immersing the learner in a scenario where she or he becomes the video game character.

For the current study, we incorporated physical and imagined embodiment in the instruction of certain Computational Thinking concepts (conditional logic, loops, and parallelism) and skills (pattern recognition, abstraction, and decomposition) during the construction of video game artifacts using Scratch, a block-based, visual programming and design language developed at the MIT Media Lab (Resnick & Brennan, 2011). Sixthand seventh-grade students from a suburban public middle school with no prior programming experience were asked to use their body to physically enact pre-defined programming scripts during four 10-minute instructional sessions over a six-day period. Instruction began with a pair of instructors modeling the physical embodiment of the pre-defined scripts, while all students observed the teachers 'being' the characters. Then, depending on the group to which they had been randomly assigned, the students either physically embodied and imagined the same pre-defined scripts themselves (see Figure 1) or only imagined these interactions, without physical embodiment. By embodying the character's actions and behaviors, the learners "became" the characters. So doing, they moved and interacted with one another in a traditional learning environment. At the same time, they created an imaged scenario that was informed by play schemas (Salen & Zimmerman, 2004). This scenario, in turn, was formed by previous game play experience and prior artifact construction (Fadjo & Black, 2011).

```
when I receive Response
say Pretty good. for 2 secs
wait 2 secs
ask Hey, did you watch the Sox game last night? and wait
broadcast Question One
```

Figure 1. Direct Embodiment of a pre-defined Scratch Script. The learner is attempting to read the pre-defined script while physically enacting the sequence of actions and statements.

In our presentation we will show split-screen video recordings of students becoming the character and engaging in the Direct Embodiment of pre-defined Scratch scripts with simultaneous tracking of sequential code structures, present findings from our recent study on using this grounded embodied approach to developing Computational Thinking and the effects these actions had on concept implementation, and discuss implications of Direct and Imagined Embodiment on the instruction of advanced computer science concepts and skills.

References

Abrahamson, D. (2004). Embodied spatial articulation: A gesture perspective on student negotiation between kinesthetic schemas and epistemic forms in learning mathematics. In D. E. McDougall & J. A. Ross (Eds.), *Proceedings of the 26th Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (Vol. 2, pp. 791 – 797). Toronto, Ontario: Preney.

Abrahamson, D. (2010). A tempest in a teapot is but a drop in the ocean: action-objects in analogical mathematical reasoning. In K. Gomez, L. Lyons, & J. Radinsky (Eds.), *Learning in the Disciplines: Proceedings of the 9th International Conference of the Learning Sciences (ICLS 2010)* (Vol. 1 [Full Papers], pp. 492-499). International Society of the Learning Sciences: Chicago IL.

Abrahamson, D., Bryant, M. J., Gutiérrez, J. F., Mookerjee, A. V., Souchkova, D., & Thacker, I. E. (2009). Figuring it out: mathematical learning as guided semiotic disambiguation of useful yet initially entangled intuitions. In S. L. Swars, D. W. Stinson & S. Lemons-Smith (Eds.), *Proceedings of the Thirty-First Annual Meeting of the North-American Chapter of the International Group for the Psychology of Mathematics Education* (Vol. 5, pp. 662-670). Atlanta, GA: Georgia State University.

Abrahamson, D., & Howison, M. (2010, April). *Embodied artifacts: coordinated action as an object-to-think-with.* Paper presented at the annual meeting of the American Educational Research Association.

Abrahamson, D., Trninic, D., Gutiérrez, J. F., Huth, J., & Lee, R. G. (2011). Hooks and shifts: a dialectical study of mediated discovery. *Technology, Knowledge, and Learning, 16*(1), 55-85.

Anderson, M. L. (2003). Embodied cognition: a field guide. *Artificial Intelligence, 149*, 91-130.

Arbib, M. A. (1991). Interaction of multiple representations of space in the brain. In J. Paillard (Ed.), *Brain and space* (pp. 379-403). Oxford: Oxford University Press.

Bakker, A., & Hoffmann, M. H. G. (2005). Diagrammatic reasoning as the basis for developing concepts: A semiotic analysis of students' learning about statistical distribution. *Educational Studies in Mathematics, 60*(3), 333-358.

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E.-J., et al. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education, 91*, 750-782.

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*, 577-660.

Barsalou, L. (2008). Grounded cognition. *Annual Reviews Psychology*, 59, 617-645.

Barsalou, L.W. (2010). Grounded cognition: past, present, and future. *Topics in Cog. Science, 2*(4), 716-724.

Bell, P., Lewenstein, B., Shouse, A., & Feder, M. (Eds.). (2009). *Learning science in informal environments: people, places, and pursuits*. Washington, DC: National Academy Press.

Benjamin, W. (1986). *Reflections: essays, aphorisms, autobiographical writings* (E. Jephcott, Trans.). New York: Schocken.

Birchfield, D., & Johnson-Glenberg, M. C. (2010). A next gen interface for embodied learning: SMALLab and the geological layer cake. *International J. of Gaming and Computer-mediated Simulation, 2*(1) 49-58.

Chan, M. S., & Black, J. B. (2006). Direct-manipulation animation: incorporating the haptic channel in the learning process to support middle school students in science learning and mental model acquisition. In S. Barab, K. Hay, & D. Hickey (Eds.), *Proceedings of the 7th International Conference of the Learning Sciences* (pp. 64-70). Mahwah, NJ: LEA.

Clement, J. J., & Steinberg, M. S. (2002). Step-wise evolution of mental models of electric circuits: a "learning-aloud" case study. *The Journal of the Learning Sciences, 11*(4), 389-452.

Coll, R. K., & Treagust, D. F. (2001). Learners' mental models of chemical bonding. *Research in Science Education*, *31*, 357-382.

Crowder, E. M. (1996). Gestures at work in sense-making science talk. *The Journal of the Learning Sciences*, *5*(3), 173-208.

Fadjo, C., Lu, M., & Black, J. B. (2009). *Instructional embodiment and video game programming in an after school program.* Paper presented at the World Conference on Educational Multimedia, Hypermedia and Telecommunications, Chesapeake, VA.

Fadjo, C. L., & Black, J. B. (2011). A grounded embodied approach to the instruction of computational thinking. In *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education*. New York: ACM.

Frederiksen, J. R., White, B. Y., & Gutwill, J. (1999). Dynamic mental models in learning science: *Journal of research in science teaching*, *36*(7), 806-836.

Gallagher, S. (2005). *How the body shapes the mind.* Oxford University Press, Oxford, UK.

Gee, J. P. (2008). Video games and embodiment. *Games and Culture*, *3*(3-4), 253–263.

Gentner, D. (1988). Metaphor as structure mapping: The relational shift. *Child Development, 59,* 47-59.

Gentner, D., & Stevens, A. L. (1983) *Mental models*. Mahwah, NJ: Lawrence Erlbaum.

Gibbs, R.W. (2005). *Embodiment and cognitive science.* New York: Cambridge University Press.

Glenberg, A. M. (2010). Embodiment as a unifying perspective for psychology. *Wiley Interdisciplinary Reviews: Cognitive Science, 1*, 586–596.

Glenberg, A. M., Goldberg, A. B., & Zhu, X. (2011). Improving early reading comprehension using embodied CAI. *Instructional Science*, *39*(1), 1–13.

Glenberg, A. M., Gutierrez, T., Levin, J. R., Japuntich, S., & Kaschak, M. P. (2004). Activity and imagined activity can enhance young children's reading comprehension. *Journal of Educational Psychology*, *96*(3), 424–436.

Goldin-Meadow, S. (2003). *Hearing gesture: how our hands help us think.* Cambridge, MA: Harvard University Press.

Goldin-Meadow, S., Nusbaum, H., Kelly, S., & Wagner, S. (2001). Explaining math: gesturing lightens the load. *Psychological Science*, *12*, 516-522.

Grafton, S., & Cross, E. (2008). *Dance and the brain*. The Dana Foundation. Retrieved October 23, 2009 from http://www.dana.org/printerfriendly.aspx?id=10744

Greca, I. M., & Moreira, A. (2000). Mental models, conceptual models, and modelling. *International Journal of Science Education, 22*(1), 1-11.

Hagendoorn, I. (2012). Inscribing the body, exscribing space. *Phenomenology and the Cognitive Sciences*, *11*(1), 69-78.

Harnad, S. (1990). The symbol grounding problem. *Physica D*, *42*, 335–346.

Harrison, A. G., Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: implications for teaching chemistry. *Science Education*, *80*(5), 509-534.

Hoffmann, M. H. G. (2007). Learning from people, things, and signs. *Studies in Philosophy and Education, 26,* 185-204.

Honey, M. A., & Hilton, M. (Eds.). (2011). *Learning science through computer games and simulations*. Washington DC: National Academies Press.

Hostetter, A. B., & Alibali, M. W. (2008). Visible embodiment: gestures as simulated action: *Psychonomic Bulletin & Review, 15*, 495-514.

Hughes, C. E., Stapleton, C. B., Hughes, D. E., & Smith, E. (2005). Mixed reality in education, entertainment and training: An interdisciplinary approach. *IEEE Computer Graphics & Applications*, *26*(6), 24-30.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason*. Chicago: University of Chicago Press.

Johnson-Glenberg, M. C., Birchfield, D., Megowan-Romanowicz, C., Tolentino, L., & Martinez, C. (2009) Embodied Games, Next Gen Interfaces, and Assessment of High School Physics, *International Journal of Learning and Media*,*1*(2). Access http://ijlm.net/knowinganddoing/10.1162/ijlm.2009.0017

Kirkley, S. and Kirkley, J. (2005). Creating next generation blended learning environments using mixed reality, video games and simulations. *TechTrends, 49*(3), 42-89.

Lu, C. M., Kang, S., Huang, S., & Black, J. B. (2011). Building student understanding and interest in science through embodied experiences with LEGO Robotics. *Educational Multimedia, Hypermedia, and Telecommunications.* Charlottesville, VA: Association for Advancement of Computing in Education.

McNeill, D. (1992). *Hand and mind: what gestures reveal about thought*. Chicago: University of Chicago Press.

Nemirovsky, R., & Monk, S. (2000). "If you look at it the other way . . .": An exploration into the nature of symbolizing. In P. Cobb, E. Yackel, & K. McClain (Eds.), *Symbolizing and communicating in mathematics classrooms: perspectives on discourse, tools, and instructional design* (pp. 177–221). Mahwah, NJ: Lawrence Erlbaum.

Newman, D., Griffin, P., & Cole, M. (1989). *The construction zone: working for cognitive change in school*. New York: Cambridge University Press.

Niedderer, H., & Goldberg, F. (1996). *Learning processes in electric circuits*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Noble, T., Nemirovsky, R., Wright, T., & Tierney, C. (2001). Experiencing change: the mathematics of change in multiple environments. *Journal for Research in Mathematics Education, 32*(1), 85-108.

Noice, H., & Noice, T. (2006). What studies of actors and acting can tell us about memory and cognitive functioning. *Current Directions in Psychological Science, 15*(1), 14-18.

Ochs, E., Gonzalez, P., & Jacoby, S. (1996). When I come down, I'm in a domain state: grammar and graphic representation in the interpretive activity of physics. In E. Ochs, E. A. Schegloff, & S. Thompson (Eds.), *Interaction and grammar* (pp. 328-369). Cambridge, UK: Cambridge University Press.

Pecher, D., & Zwaan, R. A. (2010). *Grounding cognition: the role of perception and action in memory, language, and thinking*. New York: Cambridge University Press.

Petrick, C., Berland, M., & Martin, T. (2011). *Allocentrism and computational thinking*. In G. Stahl, H. Spada, & N. Miyake (Eds.), *Connecting computer-supported collaborative learning to policy and practice: CSCL2011 Conference Proceedings* (Vol. 2, pp. 666-670). Hong Kong: ISLS.

Petrick, C., & Martin, T. (2011). *Every body move: learning mathematics through embodied actions*. Manuscript in progress (copy on file with author).

Radford, L. (2003). Gestures, speech, and the sprouting of signs: a semiotic-cultural approach to students' types of generalization. *Mathematical Thinking and Learning, 5*(1), 37-70.

Resnick, M., & Brennan, K. (2011, January 24). *Four questions about Scratch*. ScratchEd Webinar Series.

Robbins, P., & Aydede, M. (Eds.) (2009). *The Cambridge handbook of situated cognition*. New York: Cambridge University Press.

Roth, W.-M. (2001). Gestures: their role in teaching and learning. *Review of Educational Research, 71*(3), 365-392.

Rowland, T. (1999). Pronouns in mathematics talk: power, vagueness and generalisation. *For the Learning of Mathematics, 19*(2), 19-26.

Rouse, W. B., & Morris, N. M. (1986). On looking into the black box: prospects and limits in the search for mental models. *Psychological Bulletin*, 100, 349–363.

Salen, K., & Zimmerman, E. (2005). *Rules of play: game design fundamentals*. Cambridge, MA: MIT Press.

Salk, J. (1983). *Anatomy of reality: merging of intuition and reason*. New York: Columbia University Press.

Schwartz, D. L. & Black, J. B. (1996). Shuttling between depictive models and abstract rules: induction and fall-back. *Cognitive Science*, 20, 457–497.

Segal, A., Black, J. & Tversky, B. (2010, November). *Do gestural interfaces promote learning? Embodied interaction: Congruent gestures promote performance in math*. Poster presented at the annual meeting of the Psychonomics Society, St. Louis, MI.

Tolentino, L., Birchfield, D., Megowan-Romanowicz, C., Johnson-Glenberg, M. C., Kelliher, A., & Martinez, C. (2009). Teaching and learning in the mixed-reality science classroom. *Journal of Science Education and Technology.*_*18, 6*, 501-517. DOI: 10.1007/s10956-009-916.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep or a firefly: learning biology through constructing and testing computational theories—an embodied modeling approach. *Cognition & Instruction, 24*(2), 171-209.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625-636.

Wing, J. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33-35.

Wright, T. (2001). Karen in motion: the role of physical enactment in developing an understanding of distance, time, and speed. *Journal of Mathematical Behavior, 20*, 145-162.