Instruction and Embodied Design

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Abstract
We present a recent embodied-interaction instructional design, the Mathematical Imagery Trainer (MIT), for helping young students develop a grounded understanding of proportional equivalence (e.g., $2/3 = 4/6$). The implementation of this design serves as our context for developing a heuristic design framework for instructional embodied-interaction activities.

Keywords
Educational technology, mathematics education, embodied cognition, Wii remote, design-based research, design theory.

ACM Classification Keywords
H.5.2. [Information Interfaces]: User Interfaces—input devices and strategies; user-centered design; child-centered interaction.

General Terms
Design, Human Factors, Theory.

Introduction
Humans develop embodied reasoning through sensorimotor interaction in their respective environments, a capacity that has been implicated as fundamental to reasoning [3]. As learning scientists whose work intersects both theory and design, we are interested in
how students may be guided to leverage their embodied reasoning in accomplishing pedagogical tasks; and

- with embodied cognition frameworks gaining ground in instructional technology [2,4,6], how might we as a field move toward articulating a heuristic design framework for embodied-interaction activities?

**Embodied interaction**

Embodied interaction (EI) is a form of technology-supported multimodal training activity. Through engaging in EI activities, users are expected to build schematic perceptuomotor structures consisting of mental connections between, on the one hand, physical actions they perform as they attempt to solve problems or respond to cues and, on the other hand, automated sensory feedback on these actions. Emblematic of EI activities, and what distinguishes EI from “hands on” educational activities in general, whether involving concrete or virtual objects, is that EI users’ physical actions are intrinsic, and not just logistically instrumental, to obtaining information. That is, the learner is to some degree physically immersed in the microworld, so that finger, limb, torso, or even whole-body movements are not only in the service of acting upon objects but rather the motions themselves become part of the perceptuomotor structures learned. EI is not simply “hands on” but “hands in.”

As instructional activity, embodied interaction designs are often inspired by Constructivist pedagogical philosophy that draws on the genetic epistemology of Jean Piaget, the important Swiss cognitive developmental psychologist. Specifically, the design rationale of embodied-interaction instructional activities draws on the implication of goal-oriented sensorimotor interaction as mediating cognitive growth leading to conceptual knowledge. The design is further inspired by grounded-cognition research, and notably the empirically supported conjecture that human reasoning consists of simulated modal activity and not of processing symbolically encoded propositions [3].

In one form of embodied-interaction activities, representative of our work, the designers contrive a microworld wherein the physical solution actions inscribe the conceptual image of the emerging disciplinary notions. We now elaborate on one such design currently active at the Embodied Design Research Laboratory (Abrahamson, director).

**MIT: Mathematical Imagery Trainer**

We conjectured that students’ canonically incorrect solutions for rational-number problems—“fixed difference” solutions (e.g., “2/3 = 4/5”)—indicate students’ lack of dynamical action plans to ground proportional concepts. Accordingly, we engineered an embodied-interaction computer-supported inquiry activity for students to discover and practice presymbolic dynamics pertaining to mathematics of proportion.

Our instruction design, the Mathematical Imagery Trainer (MIT, see figures below), leverages the high-resolution infrared camera available in the inexpensive Nintendo Wii remote to perform motion tracking of students’ hands. We used battery-powered, hand-held IR emitters that the students point directly at the Wii camera. With LEDs repurposed from generic TV remote controls, these emitters have a wide enough angle of operation to robustly capture students’ hand motion.
The Wii remote is a standard Bluetooth device, with several open-source libraries available to access it through Java or .NET. Our accompanying software, called WiiKinematics, is Java-based and presents students with a visual representation on a large display in the form of two crosshair symbols (trackers).

When a user raises her hands at a fixed vertical distance from each other in front of our “mystery” device, the screen turns red, but when she raises her hands at a proportionately increasing distance (e.g., right hand at twice the height of her left hand), it turns green. In our research, students are tasked—individually or in pairs—to “make the screen green.”

Over the course of the interview, the MIT provides students with an opportunity to experience proportion in a controlled, progressively mathematized setting.

**figure 1.** The MIT in use by a 5th grade student during a clinical interview.

This student is holding the IR emitters at appropriate heights (2 and 4, in this case), effecting a green screen. A black matte surface on the desk helps reduce glare that can confuse the Wiimote’s IR camera into seeing two IR sources. See [http://tinyurl.com/edrl-mit2](http://tinyurl.com/edrl-mit2) for a 5 minute video clip showing the MIT in use.

**figure 2.** An example of MIT in use with crosshairs and a 1:2 ratio. A student exhibits (a) incorrect performance; (b) almost correct performance; (c) correct performance; (d) another instance of correct performance.

**figure 3.** MIT in use by a pair of students. Shown above is an advanced stage wherein students control the MIT via a table of ordered pairs.

**Towards an embodied-interaction framework**

Drawing on data from a recent study involving 4th-6th grade students interacting with the MIT [1,5], we are presently engaged with developing a theoretically coherent, empirically grounded heuristic design framework for embodied-interaction mathematics problem-solving learning activities. While grounded in
our work with the MIT, we believe the principles we have articulated thus far are general enough to apply to a range of instructional problems:

1. The designer selects/engineers a learning environment that includes a device linking simple physical actions remotely to generic virtually displayed objects.
2. The designer plans and implements mathematization-trajectory supports in the form of layerable/removable symbolic artifacts.
3. Students’ physical action should not only enable the gathering of data but actually constitute an integral component of the data. Moreover,
4. Students’ physical solution procedure has to inscribe the conceptual metaphor of the targeted mathematical notion.
5. The inquiry should be self-adaptive, not prescriptive, so that each child can gather the data they need when they need it.
6. The student should be able to move back and forth between embodied and symbolical control operations.
7. The student should be supported in coordinating among various meanings emerging from the activity by explicating relations among the different strategies they discover.

Embodied-interaction media thus appear to bear the capacity to enable student presymbolic inquiry into complex mathematical ontologies, such as proportion in the case of our work. The approach we have taken is to craft designs that manifest the target concept by creating a problem for which the physical solution procedure dynamically inscribes an innovative conceptual metaphor of the target content. While our work is in its early stages, we hope to have conveyed some of our enthusiasm over the instructional possibilities offered by embodied interaction technologies. Our future work will continue to seek improvements in both theory and design.

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References