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Gesture Enhancement of a Virtual Tutor via Investigating Human Tutor Discursive Strategies: Forms and Functions for Proportions

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Abstract: We examine expert *human* mathematics-tutor gestures in the context of an interactive design for proportionality in order to design a *virtual* pedagogical agent. Early results implicate distinct gesture morphologies serving consistent contextual functionalities in guiding learners towards quantitative descriptions of proportional relations.

Towards a Virtual Pedagogical Agent Capable of Instructional Mathematics Gesture

Mathematics teachers spontaneously employ gesture as spatio-dynamic complements to verbal and symbolic utterance (Alibali et al., 2014), and a growing body of work emphasizes such multimodality as an essential dimension of instructional practice (e.g., Arzarello et al., 2009). However, to date, virtual pedagogical agents (VPAs) embedded in teacher-independent mathematics tutorials *lack instructional gesturing capacity*. Our NSF-funded CyberLearning EXP design-research project seeks to integrate an animated, gesturing VPA with The Mathematical Imagery Trainer for Proportion (MIT-P), an embodied-learning device (Abrahamson et al., 2012).

The MIT-P was designed to provide an interactive context for students to ground proportionality in a sensorimotor scheme. Students first discover an operatory schema for achieving a non-symbolical goal state of a technological device—in Figure 1 this state is "green"—and then signify their strategy mathematically. The human tutor guides learners through the discovery of green-making hand movements and then facilitates a sequence of shifts in their green-making strategies toward a mathematical register. Each of these shifts is onset, formed, and enabled by a new symbolic artifact the tutor introduces onto the screen (cursors, a grid, numerals).

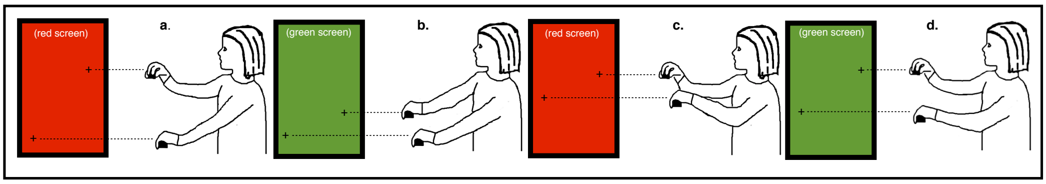

Figure 1. When the Mathematical Imagery Trainer for Proportion (MIT-P) is set to a 1:2 ratio, the right hand needs to be twice as high as the left hand in order to make the screen green. Learners receive green feedback when hand heights embody a 1:2 ratio (b, d) and red feedback when hand heights depart from this ratio (a, c).

The Construction of a Classification Scheme of Human Tutor Gesture

To design the VPA, we are collaborating with animation specialists from the UC Davis Motion Lab who will create a virtual, gesturing character according to our pedagogical specifications. Because the VPA will be limited to a finite repertoire of gestures and vocalizations, our early task is to schematize the most consequential multimodal tactics human tutors employ in the MIT-P context for the animation team to render. Towards this goal, we are examining form ("what") and function ("*for* what") of human tutor gestures in our corpus of 23 video-recorded task-based interviews with Grade 4-6 students. The need to parameterize gestures *for simulation* has necessitated that we develop new methods for accurately and systematically articulating expert tutor gesture. To this end, our analysis of human tutor gestures attends to: (1) their occurrence in the temporal context within the tutorial sequence; (2) their spatio-dynamic morphology (e.g., hand shapes); (3) their coupling with focal artifacts (e.g., computer monitor); and (4) their service as a MIT-P tutorial tactic (Abrahamson et al., 2012). We propose that items 2 and 3 describe gesture *form* while 1 and 4 are descriptors of its *function*. Below, we present cases that highlight gestural variation observed during three critical phases of the interviews.

Distinct Forms of Pedagogical Gestures Contribute to Common Functions

As students embark on their initial explorations of the conditions that make the screen green, an early function of tutorial gesture is to encourage learners to explore novel spatial regions of the screen (Figure 2, A1-3). Later, a second function of tutor gesture is to highlight latent properties of the logico-quantitative relationship between the two cursor heights (Figure 2, B1-3). Still later, as students begin to describe the underlying interaction pattern quantitatively, tutor gestures become components of revoicing student strategies, such as in illustrating the iterative-additive and multiplicative relationships (Figure 2, C1-3). As illustrated in Figure 2, however, the forms of each of these instructional-gesture functions may be diverse in terms of spatio-dynamic morphology and coupling (or lack thereof) with environmental focal artifacts. Despite this diversity in gestural component,

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each of the distinct forms bears its desired functional effect in prompting further exploration, eliciting preliminary relationship hypotheses, and supporting more detailed articulations of quantitative relationships.

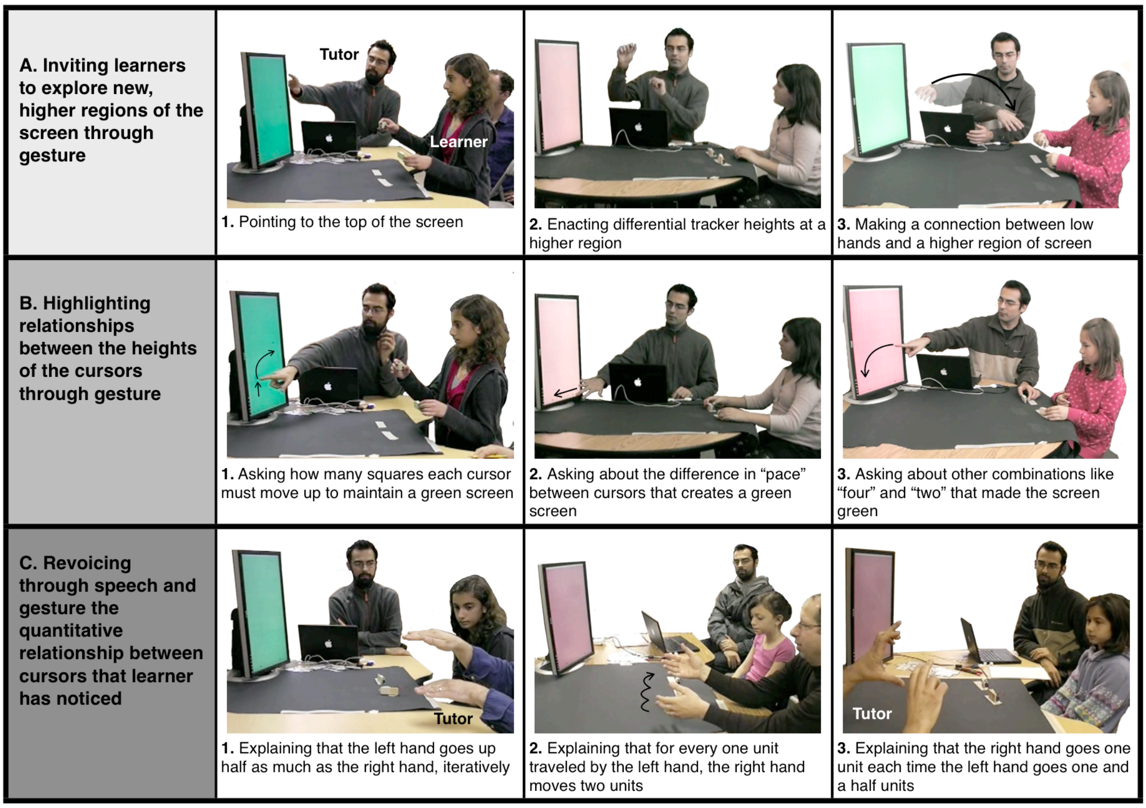

Figure 2. Three functions of MIT-P tutor gestures and their distinct forms.

Conclusions, Implications, and Benefits of Design Work

Developing a taxonomy of gestural aspects of tutorial tactics so that they may be rendered in animation has caused us to re-attend in new ways to both gross and minute variation in gestural form and has consequently propelled our discovery of distinct gestural forms bearing similar function. Past work on instructional gesture in mathematics learning settings emphasizes the *similarity* of gestural forms serving similar broad functions (e.g., "linking episodes" in Alibali et al., 2014). However, we emphasize the nuanced *variety* of gestural forms for the same highly specific functions. This morphological variety in form across functionally isomorphic gestures, we submit, promotes student understanding by evoking differentiable configurations of available semiotic interactional resources (e.g., depicting different spatial metaphors for the same mathematical idea; see C2 and C3 in Figure 2). Thus, a primary benefit of the taxonomy we generate for the specific purpose of designing our VPA may be its ability to reveal and highlight potentially critical features of instructional gesture that have been previously inaccessible to coarser categorization schemes.

A secondary benefit of our analysis was the design and production of a novel system for the efficient capture and representation of dozens of morphologically unique semiotic bundles (Arzarello et al., 2009). Our solution was to create a comprehensive GIF-clip library (Figure 3) of re-enacted human tutor pedagogical choreographies based on reproductions of the authentic tutorial tactical moves. This technique allowed us to preserve and organize the many variable forms of gestures by function for their future simulation.

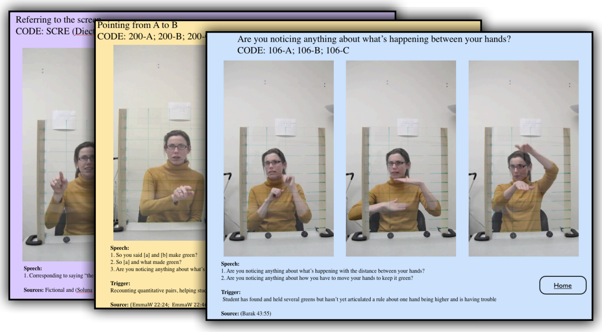

Figure 3. Selections of GIF-clip library of re-enacted pedagogical gestures for mathematics

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