

ISGS 2016

THEMATIC PANEL TITLE: Gesture production in virtual pedagogical agents

## Summary of the Thematic Panel

**Words = 450**

Learning and teaching are social and embodied. Gesture, therefore, plays a valuable role in the design of effective learning environments. This thematic panel brings together scholars from a variety of institutions and scholarly perspectives to present research on the nature of gesture as it is implemented in avatars and virtual pedagogical agents for mathematics and language learning.

People regularly and spontaneously engage their hands and arm movements along with speech as part of their communication. These *gestures* are ubiquitous during natural conversation (Kendon, 2004; McNeill, 1992). In addition, a meta-analysis of 63 studies (Hostetter, 2011) concluded that speakers' gestures benefit listeners' comprehension, especially children. Gestures are also prevalent during classroom instruction (Alibali et al., 2014; Richland et al., 2007). Furthermore, teachers regulate their use of gestures to suit the needs of their students (Alibali & Nathan, 2007; Alibali et al., 2013). Instruction that incorporates effective gesture practices can foster greater learning than lessons without it (e.g., Church, Ayman-Nolley & Mahootian, 2004; Alibali et al., 2013). So it is natural that designers of digital learning environments investigate virtual pedagogical agents that incorporate use of effective instructional gestures.

Each of the panelists is developing rich theoretical, methodological, and practical aspects of gesture research for advancing our understanding of the design of effective learning environments. In addition to presentations on the power of gesture to enhance learning, comprehension, and transfer, this session will explore two crosscutting topics important to the advancement of virtual pedagogical agents:

*Topic 1.* Gestures make ready use of resources in one's environment (e.g., one's body, objects and inscriptions, locations in shared space) to enhance comprehensibility and learnability. What makes gesture special for learning?

*Topic 2.* Instructional gestures for pedagogical agents can be encoded as general pedagogical principles (Paper 1); specific, verbally scripted actions (Papers 2 and 3); and image-based reenactments (Paper 4). How does the level of description used to encode pedagogical gestures influence student learning?

The first presenters (Alibali, Nathan, Popescu & Yeo) will describe empirically based principles of effective instructional gestures that drive the design of a virtual pedagogical agent for making connections among mathematical ideas and fostering common ground. The second (Pruner, Popescu, & Cook) presents findings showing enhanced learning, transfer, and generalization of arithmetic learning from the gestures produced by a virtual agent that integrates charismatic and cognitive considerations. The third (Bergmann, Aksu & Rosenthal-von der Pütten) shows enhanced language learning from a virtual pedagogical agent that uses iconic gestures. The fourth (Flood, Neff & Abrahamson) investigates animated-GIF banks to capture pedagogical

gestures and communicate gestures to teachers. The assembled scholars each offer important insights into the power and challenges of integrating pedagogical gesture into the design of the next generation of digital learning environments.

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## Effective Instructional Gestures: Design Principles for Virtual Pedagogical Agents

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**Words: 437**

Gesture benefits comprehension (Hostetter, 2013) and classroom learning (Alibali et al., 2013). As scholars and developers collaborate to design and implement virtual pedagogical agents for embodied, multimodal instruction, there is a need to identify principles for effective instructional gestures (Cassell, 2000). The literature covering naturalistic observational studies of teachers, laboratory research, and classroom teaching experiments supports several principles for effective gesture use. We focus here on three principles that guide the design of our virtual agent for mathematics instruction (Figure 1): Teaching is multimodal, with gestures playing a central role; pointing and highlighting index ideas to the world; and coordinated sequences of gestures are used to form links, which connect ideas and forge common ground with students. Together these principles provide guidelines for effective gesture in pedagogical avatars.

First, teachers regularly use gesture as part of their multimodal communication to students (see Figure 2) (Edwards, 2009; Flevares and Perry, 2001; Roth, 2001). For example, when teachers communicate connections between mathematical ideas, they almost always express them multimodally, usually including gestures (Alibali et al., 2014). Furthermore, teachers increase

their use of gestures when communicating new as compared to review material (Alibali et al., 2014), and when responding to students' expression of confusion or trouble spots (Alibali et al., 2013; Nathan & Alibali, 2011).

Second, teachers index ideas and representations to the world via pointing and other highlighting acts (Figure 3). These indexical forms relate ideas to objects and places in the learning environment (Alibali, et al., 2013; Richland, 2008). Indexical gestures are often *ground* abstract or unfamiliar ideas and inscriptions in the physical environment, in order to scaffold students' sense-making processes (Nathan, 2008; Walkington, et al., 2013). Consistent with scaffolding, the frequency of indexical gestures decreases (fading) as the ideas and inscriptions become more familiar to students (Alibali & Nathan, 2007).

Finally, teachers regularly coordinate multiple gesture-speech acts to establish links among mathematical ideas and representations (Figure 4). Links that specify relationships among ideas play a central role in mathematics lessons, because the meanings of mathematical entities often depend on relational semantics (Kaput, 1989). In a corpus analysis (Alibali et al., 2014), middle school mathematics teachers produced an average of more than 10 links per hour of instruction. Gestures served a linking function most often when mathematical ideas were first mentioned, even if they were part of a review, and when students encountered new, abstract information, such as a new formalism.

In this paper, we demonstrate how we have implemented these principles in the gestures of a computer-based avatar teacher, and we describe a program of research aimed at investigating the role of such gestures in student learning.

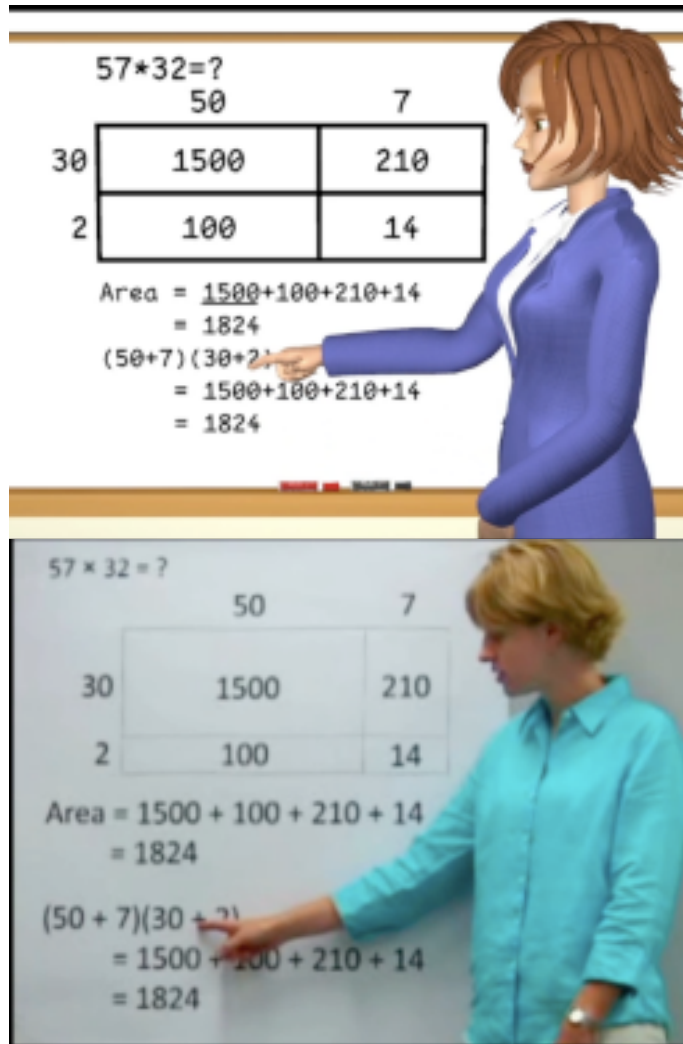


Figure 1. Our prototype avatar (top) and its model (bottom), which provides instruction that incorporates our three instructional principles: multimodal communication using integrated speech, gesture and writing; contextually relevant pointing and highlighting to index ideas to the world and ground unfamiliar concepts; and coordinated sequences of gestures form links that connect ideas and foster common ground with students.



Figure 2. Drawing of a human teacher performing multimodal instruction using gesture, speech, and object manipulation

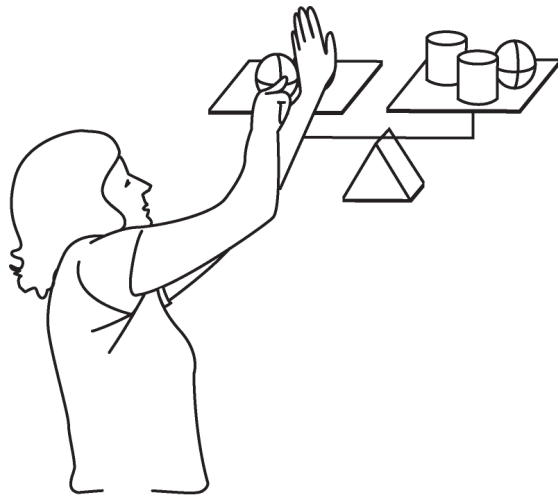


Figure 3. Drawing of a human teacher using indexing and highlighting.



Figure 4. Drawing of a human teacher using linking to express the connections between mathematical entities, corresponding sides of similar quadrilaterals.

### **The effect of temporal coordination on learning from speech and gesture**

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**Words = 422**

Hand gesture can improve learning in children (Goldin-Meadow and Wagner, 2005). The beneficial effects of gesture can be seen in a number of domains, including language development (Ozcaliskan & Dmitrova, 2013), number conservation (Ping & Goldin-Meadow, 2013), and mathematical equivalence (Cook, Duffy, & Fenn, 2013). In spite of gesture's beneficial effects, it is not clear exactly what it is about gesture that benefits learners. Gestures have a number of characteristics that might be especially useful for learners. Gestures represent information visually, using the body, and many researchers have hypothesized that gesture's benefit is due to its unique representational affordances. However, gestures are also temporally coordinated with speech and so some of their benefit might be due to their precise timing. We manipulated the temporal coordination of information across speech and gesture to assess whether learners are sensitive to the synchrony of information across modalities

We used an animated teaching agent (ATA) in order control for potential confounding factors including eye gaze, body position, and intonation, which typically covary with gesture.

More importantly, by using an ATA, we were able to manipulate gesture timing while maintaining coordination of the lip movements and the spoken explanation.

Children participated in one of three gesture conditions. In the Original condition, we used stimuli based on Cook, Friedman, Duggan, and Cui (in press), which were previously demonstrated to benefit learning when compared with a non-gesturing ATA. The gestures in Cook et al. were timed to look natural according to the researchers' intuitions. In the Early or Late conditions, the timing of the gestures from the Original Condition was manipulated, with the gestures shifted 500 ms in either direction. After viewing the instruction, children completed three tests of understanding. Children wore a head mounted eye-tracker throughout the experiment.

For those children who were not successful on a pretest, children in the Early and Original conditions outperformed those in the Late condition,  $z = -1.73$ ,  $p = .08$  (see Figure 1). Children in the Early condition performed better than those in the Original condition, but this difference was not reliable.

These findings suggest that learners benefit most from gestures that are most like those spontaneously produced, where gestures anticipate, or coordinate with the accompanying speech. These findings also have clear implications for the design of instructional materials. The principle that visual information should not lag behind auditory information may apply more generally to multimodal instruction. Indeed, in studies of audiovisual integration, greater integration is seen when visual information precedes auditory information than the reverse (Sekuler, Sekuler, & Lau, 1997).

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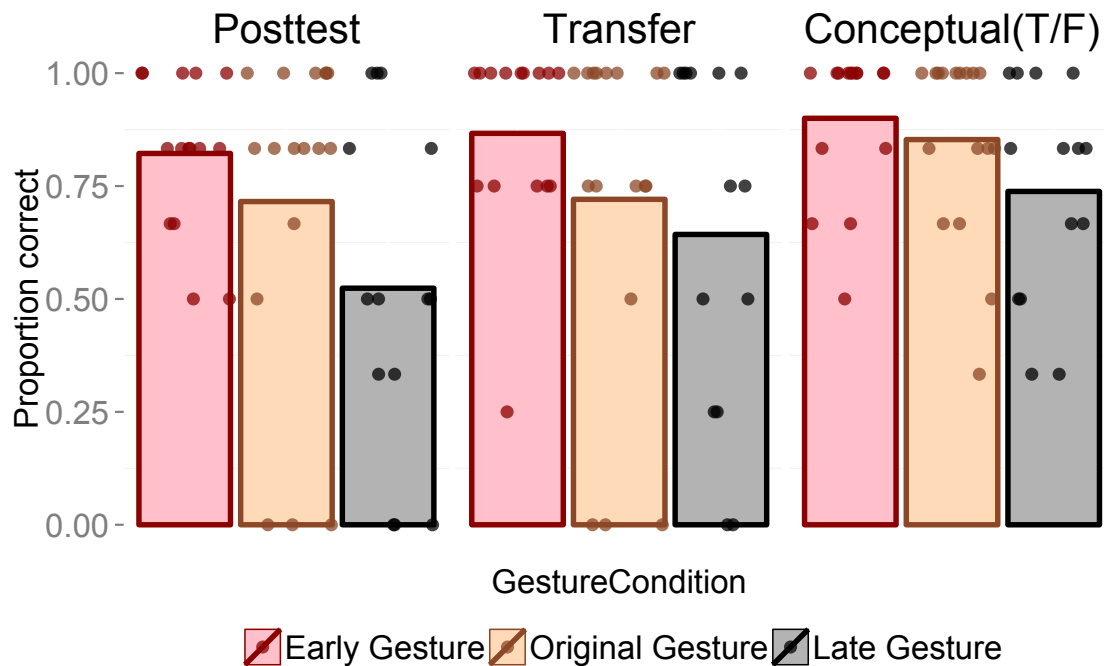


Figure 1. Children's proportion correct on the Posttest, Transfer, and Conceptual tests. Each dot represents the performance of a single child in the experiment.

### Vocabulary Learning with a Virtual Agent -- The Role of Non-verbal Aids and Individual Differences

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Words: 433

For the domain of foreign language vocabulary learning, increasing evidence suggests that iconic gesture performance together with a novel word, enhances learning and makes those words more resistant against forgetting (cf. Hald et al. 2015). At the same time the multimedia principle (Mayer 2009), stating that learning with textual content and pictures is more effective than learning with textual materials alone, has received robust empirical evidence also in the domain of vocabulary learning (cf. Butcher 2014).

Along these lines, learning environments incorporating embodied agents provide a flexible way to support vocabulary learning with non-verbal means – be it by gestures or by pictures. A first study testing gesture-based vocabulary training with a virtual trainer actually showed similar beneficial effects on learning outcome as a real human trainer (Bergmann & Macedonia, 2013). Empirical evidence, however, to decide in favour of one or the other non-verbal aid, is rare and not fully conclusive (Tellier 2008; Rowe et al. 2013; Mayer et al. 2015). This might be due to



different training or test procedures employed in the studies, but might also be caused by individual differences among learners. In fact, there is evidence demonstrating that learners' verbal skills and gender can modulate word learning performance (Rowe et al. 2013; de Nooijer et al. 2014). In the present study, we tested the influence of individual language learning styles (Oxford 2003, p. 1) to investigate how well students learn a second or foreign language from a virtual agent using different non-verbal learning aids

We conducted German-Finnish vocabulary training with a virtual human, combining a within-subject manipulation of training type (words+gesture, words+picture, words-only) with an assessment of participants' language learning style (Style Analysis Survey, Oxford 1990). The virtual human was present in all conditions. In the words+gesture condition, participants imitated the agent's iconic gestures. In the words+picture condition, participants additionally saw a picture depicting the words' meaning. Both gestures and pictures had been evaluated in a pre-test to be semantically congruent with the words to be learned. 30 participants learned 15 word pairs per condition in three sessions over consecutive days. Learning performance was measured one day after each learning session, respectively (short-term measures) and again four weeks after the training period (long-term measure).

Results showed both short- and long-term effects of training type. In the short-term, gesture- and picture-enrichment outperformed the baseline, whereby memory performance differed by several dimensions of language learning style. In the long-term, however, gestures turned out to be most beneficial – irrespective of individual learning style. These findings further strengthen the role of gesture use in vocabulary learning, especially when it comes to sustain learning progress.

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## Animated-GIF libraries for capturing pedagogical gestures: An innovative methodology for virtual tutor design and teacher professional development

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Words = 443

We report on a novel approach for archiving repertoires of multimodal pedagogical techniques that enlists animated Graphic Interchange Format (GIF) files. This methodology was developed by an interdisciplinary team of learning scientists (LS-team) and computer scientists (CS-team) building a virtual, animated, mathematics tutor capable of multimodal communication.

Using an extensive video corpus of mathematics instruction, the LS-team identified a repertoire of pedagogical gestures for the CS-team to simulate virtually in the animated character. However, early on, the LS-team struggled to communicate this repertoire. Video clips of pedagogical gestures occurring “in the wild” were over-situated in the idiosyncratic spatial configurations of their environments (Goodwin, 2007) and could not delineate the generic, core specifications of the gestures to be reproduced. At the same time, the complex trajectories and morphologies of these gestures did not reduce well to verbal description with static images. Spontaneous, situated motion is notoriously difficult to inscribe (Guest, 1998). Of the various gesture classification schemes currently available (Kendon, 2004), none offer a level of specificity necessary for accurate three-dimensional, dynamic reproduction.

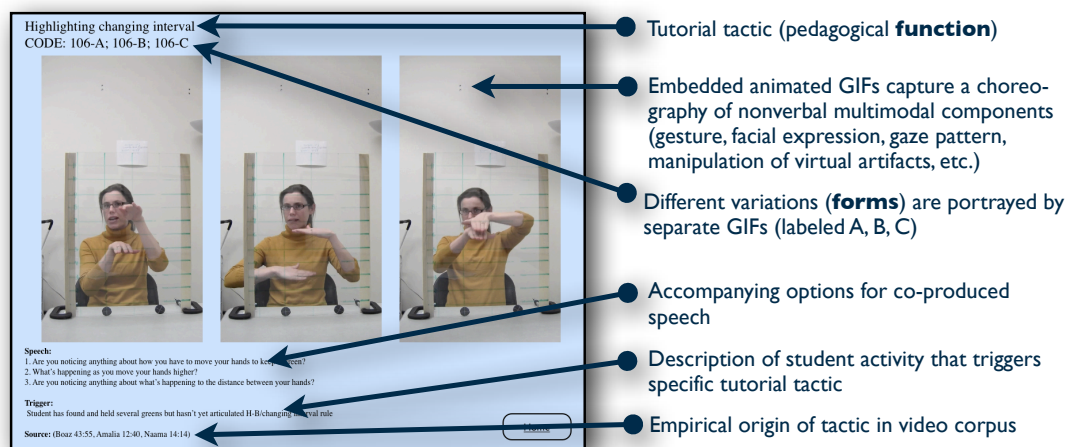


Figure 1. A sample entry from the library of animated-GIFs of instructional gesture

The solution we developed bypassed the need to represent gestures with either static inscription or *in situ* video clips. We created a digital library of animated-GIFs of re-enacted gestures (Figure 1) and succeeded in using this library to support an actor's motion capture performance (Figure 2). By re-enacting gestures from the video corpus, we were able to create idealized, contextually generic forms of the spontaneous gesturing techniques we observed in learning settings. Animated-GIFs unequivocally convey the three-dimensional, dynamic details of each gesture, allowing a viewer to quickly and accurately learn the form. An unexpected benefit is that animated-GIFs also capture other critical semiotic resources of the multimodal

Gestalts (Mondada, 2014) that accompany gesturing such as patterns of gaze and facial expressions (Streeck, 2009).

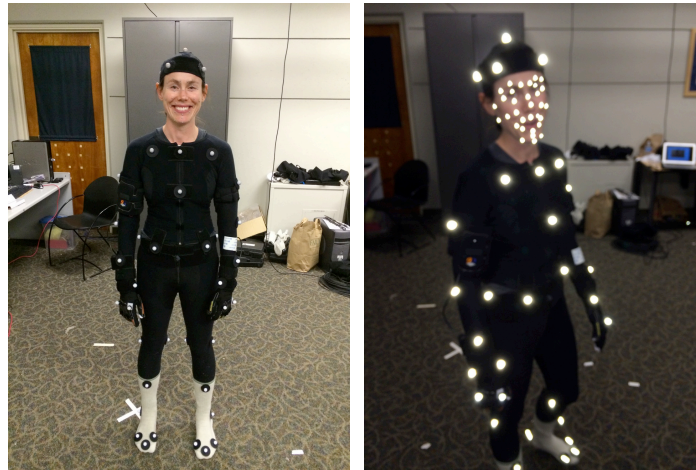


Figure 2. An actor performs the animated-GIF gesture library during a motion-capture session

There is strong consensus that teacher gesture during instruction is essential for students' learning (Nathan & Alibali, 2011), and therefore there is a growing need to develop materials to support teachers in effective use of multimodality in lessons. Currently, common gesture annotation systems - verbal narratives and static images with multiple elaborate arrows - leave too much spatio-dynamic information (e.g., trajectory) ambiguous. Teachers working from such illustrated scripts cannot faithfully reenact the original movements. Animated-GIF libraries of reenacted pedagogical gestures are clearly depictive, circumvent privacy issues, and can be stored in broadly accessible formats (e.g., web). Therefore, we believe our animated-GIF banks present exciting possibilities for productively disseminating pedagogical gesturing techniques directly to in-service and pre-service teachers as part of professional development.

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