Broadening What We Perceive: An Introduction to Research Methods For Analyzing Gesture and Language

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Abstract: Gesture and language are deeply intertwined, and attending to both simultaneously when examining mathematical processes is a complex yet rewarding task. We share our budding research methodology for analyzing gesture and language and discuss the methodology from a generic perspective that can be easily adapted to different contexts, participants, and mathematical domains. We further share our problem-specific gesture coding scheme as an example of the grain size and foci of such schemes. Finally, we close by discussing the importance of gesture and language to understanding mathematical justifications and proofs.

Keywords: Research Methods, Geometrical and Spatial Thinking, Reasoning and Proof.

Gesture and language are deeply intertwined: both provide channels for communicating thoughts and ideas, facilitating intersubjective understanding, and supporting various modes of cognition. Language is integral to mathematics (e.g., Hersh, 1999), as it can trace one's thinking and reveal the structure of logical and empirical thought. We often privilege linguistic and propositional accounts over other forms of mathematical and scientific reasoning (Baird, 2004; Nathan, 2012). Yet, physical manifestations of thought in the form of gesture are deeply connected to verbal language (Goldin-Meadow, 2003; McNeill, 1992; Radford, 2009). In earlier work (Authors, 2012), we reported on how gestures can exhibit "invisible proof" schemes that reflect analytic thought in nonverbal ways. Both gesture and spoken language contribute to multimodal channels (Arzarello, Paola, Robutti & Sabena, 2009) for communicating mathematical justifications and proofs, but their individual contributions can be difficult to synthesize and understand. In this work, we describe a methodology for developing problem-specific coding schemes for analyzing language and gesture separately and together during mathematical activities. The method, currently in use, is also evolving as we apply it to new data. A fully tested and refined version will be presented at the PME-NA Meeting.

In the spirit of the PME-NA 2013 theme, *Broadening Perspectives on Mathematics Thinking and Learning,* this work focuses on how to achieve more nuanced insights into reasoning processes by considering gesture alongside verbal acts. We aim to provide a methodology that others can repurpose to their own ends. In the following sections, we discuss embodied cognition and its link to mathematical reasoning, and briefly share details of the research project that motivated the development of this methodology. We then detail the *generic elements* of our methodology for analyzing video and audio data generally, and then present the *problem-specific* gesture coding scheme we have developed. We conclude by connecting our research and methodology to advances in mathematical reasoning and proof practices.

Theoretical Framework and Motivation

Theories of embodied cognition posit a relationship between action and cognition (Shapiro, 2011), refuting the traditional view of cognition as composed of amodal symbol systems and instead regarding the action and perception systems as inextricably bound to thought processes (Barsalou, 1999; Barsalou, 2008; Glenberg & Robertson, 2000; Wilson, 2002). Speakers' gestures are also viewed as necessarily tied to action (Hostetter & Alibali, 2008), and as such, gestures provide evidence for the embodiment of thought. Alibali and Nathan (2012) connect theories of embodied cognition and gesture with mathematics learning, arguing that, "gestures thus provide a unique and informative source of evidence regarding the nature of mathematical thinking" (p. 274). So how can mathematics education rigorously and consistently unpack this "unique and informative source?" We developed this methodology to: identify the types of gestures that co-occur with various types of mathematical reasoning, determine how gestures support desired reasoning, and document new insights from attending to gesture and language.

Design

We conducted an experiment with 120 undergraduate students at a large, Midwestern university. Students were asked to justify and prove mathematical conjectures involving concepts from number and geometry. In this paper, we focus on a triangle conjecture:

Mary came up with the following conjecture: For any triangle, the sum of the lengths of any two sides must be greater than the length of the remaining side. Provide a justification as to why Mary's conjecture is true or false.

Prior to reading the conjectures, participants were asked to perform physical actions that were designed either to support solving the conjecture or to be irrelevant to the solution. We also varied the scale of the actions they were asked to perform, which has demonstrated importance in mathematics-related gestures (e.g., Gerofsky, 2009). For the triangle conjecture, participants formed a triangle either with their hands (*observer* scale, in which gestures are produced from a third-person perspective) or with their arms outstretched (*character* scale, in which the speakers' body becomes the character or object being described) (McNeill, 1992). Participants were directed to stand and to share their reasoning out loud. In this work, we are focusing on a subset of the data corpus: the 40 participants who solved the triangle conjecture in the irrelevant action condition, with half from each scale condition (i.e. observer vs. character).

Methodology

We present a step-by-step summary of our generic methodology for analyzing language and gesture simultaneously. It is *generic* because it can be readily tailored to answer other research questions and apply to different mathematical tasks. Throughout this section, we provide an example from a single participant solving the triangle conjecture to exemplify the methodology (Table 1).

Generic Methodology

Our coding process is iterative and utilized several features of the Transana software platform. The first step involves using only the transcript and audio channels (i.e., no video) to segment the verbal stream into *speech bursts*, or continuous speech with no small pauses. Second, we code the *speech fluidity* of each segment using the audio, transcript, and waveform data, the last of which allows us to visually detect breaks in the audio stream. Speech fluidity is the degree to which a participant speaks quickly and smoothly, and our codes range along the fluidity spectrum to include: Fluid, Choppy, Slow, etc. Third, we note the number of *words per speech burst* as an additional, quantitative measure of speech fluidity.

Fourth, we code the *prompt response* at the speech burst level, using the transcript and audio. This is dependent on the specific question or prompt that the participant is responding to during the task. In the example, the participant is asked to explain whether the conjecture is true or false; thus, our code for prompt response is “True” or “False.” This category allows us to note whether the participant is attempting to prove or disprove the conjecture, and to identify any shifts in this direction over the course of the task.

Fifth, we note the *gesture description*, *gesture code* and the gesture *length*, using the video feed, audio feed, and transcript in conjunction. Gesture description is an open-ended description of the participant’s action, and gesture code assigns a problem-specific code, as explained in the following section. To code gesture length, we use both the dichotomous qualitative categories of Fleeting or Extended (*Length* column) and a quantitative measure of duration of the gesture in seconds (*# sec* column).

Relying only on video, we next code for the *gaze* of the participant. Finally, the gesture *scale* is coded as Observer or Character using only the video.

Table 1: Analysis Excerpt (Participant G_104_Triangle)

Speech Burst	Speech Fluidity	Words/ Burst	Prompt Resp.	Gesture Description	Gesture Code	Length	# sec	Gaze	Scale
If it was like this, um	Fluid	5	True	L palm on top of R, R fingers & base of palm touch L	Forms complete triangle, 2 Hands	Ext.	1	At hands	Obs.
these two sides couldn’t ever be, uh	Choppy	6	True	L index finger points to 2 sides of R hand tri.	Traces 2 sides of a triangle, single finger	Fleet.	1	At hands	Obs.
less than this. Because if they were even to it, it would be a straight line.	Fluid	22	True	Palms flatten against each other	Forms incomplete triangle, 2 Hands	Ext.	6	At hands	Obs.

Here, participants were not provided with any additional supports or tools for justifying the conjectures. However, when we use this methodology in contexts in which participants have access to such materials and representations, we add additional categories for: (1) objects/tools in use during a speech burst, and (2) actions performed with objects/tools during a speech burst.

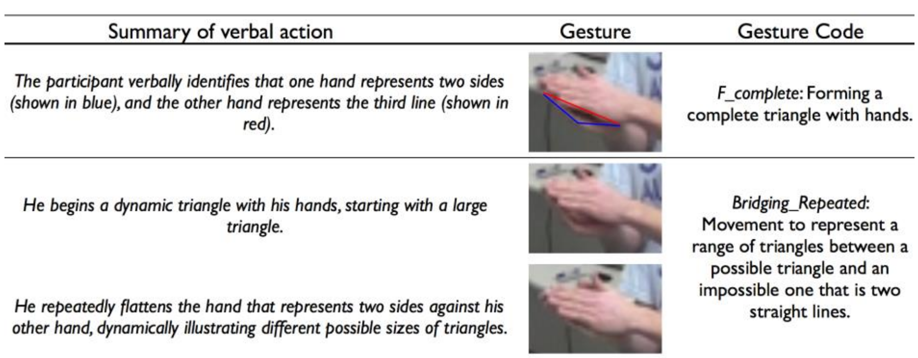

Figure 1: Sample Triangle Gestures and Codes (Participant G_104_Triangle)

Problem-Specific Gesture Coding Scheme

Our *problem-specific* gesture coding scheme was developed through repeated viewing and analysis of the data, and is based upon the Triangle Inequality conjecture. We use three broad coding categories: *tracing*, *forming,* and *bridging*. Tracing refers to gestures that are coherent only when viewed over the full course of the gesture (e.g., tracing a triangle in the air with a finger). Forming gestures, however, represent the entire object simultaneously (e.g., first row in Fig. 1). Each of these two categories includes multiple subcategories, including depicting a single line, a complete triangle, or an intentionally incomplete triangle. For each gesture, we also code which body part(s) were involved in the gesture, noting the number of fingers, hands, and/or arms. Our third code, *bridging* (e.g., second row in Fig. 1), refers to dynamic representations of multiple triangles within the same gesture. Participants' use of bridging action is particularly intriguing because it involves a single gestural act to reason inductively.

Connecting to Reasoning and Proof

Practices of mathematical justification could be viewed as having two interwoven phases: one in which students figure out for themselves by reasoning through the relationships (*ascertaining*), and one in which they must communicate a convincing argument to a third party (*persuading*) (Harel & Sowder 2005). Our methodology is useful for characterizing phases of ascertaining and persuading by looking at indicators such as gaze, speech fluidity, and shifts in prompt response. These phases can be cross-referenced with gestures to identify the critical ways in which the body can support learners in reasoning about and communicating mathematical ideas, as well as how gestures correspond to important mathematical insights. Although it is generally accepted that gesture is integral to communication, the more novel idea that gesture triggers changes in cognitive states during reasoning is growing in importance in mathematics education research (e.g., Authors, in submission; Goldin-Meadow, Cook, & Mitchell, 2009).

Conclusion

Our work is progressing into identifying "invisible proof" practices (Authors, 2012), and thus, we have shared our methodology so that others can also begin to examine the relationships between language and gesture in mathematical communication. Research on gesture includes many examples in which gesture provides information that differs from speech, including cases of gesture-speech mismatches (e.g., Church & Goldin-Meadow, 1986). Previous research has identified some of the connections between mathematics learning and gesture (Alibali & Nathan, 2012; Abrahamson, 2004). We aim to advance the field by identifying a methodology to examine how reasoning processes can be better understood through a focus on gesture.

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