Research in Science Education: The Role of Gestures in Geoscience Teaching and Learning

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INTRODUCTION

Gestures are an integral part of communication among people of all ages and cultures. People gesture during spontaneous conversations with friends. Teachers gesture when explaining a scientific concept to a class. Students gesture as they work together when learning a new scientific principle. So do scientists during "lab-talk."

Research has shown that gestures are not merely idle arm-waving; they are profoundly connected to cognition and perception, and can convey subtle meanings that would be awkward or impossible to convey in language alone. For an educator or education researcher, gestures can therefore provide a window into students' thought processes, even when the students do not articulate their understandings or misunderstandings in words.

This column reviews seminal research on gestures in the domains of problem solving, science education, field-based education, spatial tasks, and scientists' discourse. We present evidence that gestures are of value for both gesturer and recipient, review hypotheses about why gestures are valuable, analyze examples of gesture as used by both instructors and students while discussing geoscience topics, offer suggestions for geoscience educators, and conclude with directions for future research.

EVIDENCE THAT GESTURES ARE BENEFICIAL FOR BOTH GESTURER AND RECIPIENT

Research has shown that gestures aid both the communicator and the recipient. In one illustrative study, college students were asked to assemble a TV cart using a photograph as a guide, and then make a video explaining how to assemble the cart (Lozano and Tversky, 2006). One group was allowed to both speak and gesture as they made the video. A second group was told that they were making the video for non-English speakers and thus could use only gestures and actions, no speech. A control group merely assembled the cart a second time, without making a video. The videos were shown to new students, who were then asked to assemble the cart. As judged by number of errors during assembly, the students who viewed gesture-only videos significantly outperformed the students who viewed speech-and-gestures videos. Thus gestures were shown to be beneficial for the recipient. The students who had made the videos were then surprised by a request to re-assemble an identical TV cart. Remarkably, the gesture-only group significantly outperformed the gesture-and-speech group, and greatly outperformed the control group, in terms of number of errors made during reassembly. Thus gestures were shown to be beneficial for the gesturer as well as the recipient.

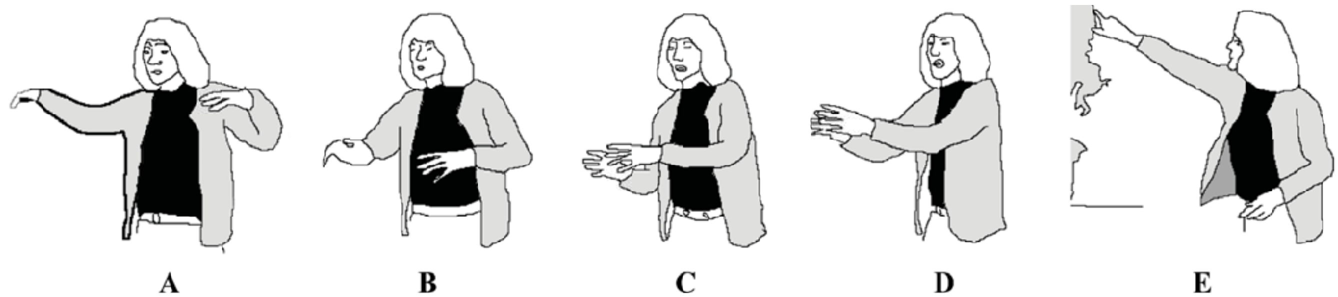
Several other lines of research support the contention that gestures benefit gesturer, recipient, or both, especially on spatially-demanding tasks. Raucher, et al. (1996) found that people who were prevented from gesturing while speaking about spatial content produced more dysfluencies per word than those who were allowed to gesture naturally. Erlich, et al. (2006) showed that children who produced movement gestures while explaining how they solved a spatial transformation problem answered more test items correctly than did those who did not make such gestures. Similarly, Cook and Goldin-Meadow (2006) showed that children who gestured while explaining how they solved math equivalence problems answered more post-test questions correctly than children who did not gesture. Goodwin (2007) documents instances in which archeologists' discussions in the field are incomprehensible if gestures and objects in the world are not considered as integral and essential components of the communication, and Roth (2000) makes much the same case for students in a physics laboratory.

WHY ARE GESTURES BENEFICIAL?

Researchers who address this question draw distinctions among several types of gestures (McNeill, 1992), each of which has different uses. Here we focus on two: (1) "Deictic gestures" indicate entities, objects, direction, or other phenomena within the conversational space, usually by pointing. (2) "Iconic gestures" resemble some aspect of the referent that is being portrayed, such as shape of a structure, orientation of objects, or trajectory of movements through space.

Deictic gestures help recipients by focusing their attention to entities in the conversational space that the speaker/gesturer considers to be worthy of attention (Lozano and Tversky, 2006; Roth and Lawless, 2002). This is of value because vision delivers far more information than the human mind can process in depth, so humans allocate their attention strategically, fully attending to only a few of the objects available in the visual field at any moment (Rensink, et al., 1997). In science education, attention-focusing is especially important when the visual field is intricate (for example, an outcrop or satellite image) or unfamiliar (for example, a graph of a novel data type).

Iconic gestures can help the recipient in several ways. First, because gestures occur in three dimensions (Roth, 2000), they can show, rather than tell, the recipient about attributes of 3-D structures and processes: their shape, size, position, direction, and orientation. Secondly, because gestures play out over time, they can show 4-D information: trajectory, velocity, acceleration,



So this is basically a drainage area that is collecting the water *[Her arms make several slight pumping gestures]* (A) that falls on the lands *[Elbows and forearms descend]* (B).

…and it is all *[Steps forward and the hands come together]* (C).

…funneling down the stream *[Hands and arms move forward, hands wiggle to enact meandering]* (D) and ultimately into Saanich Inlet *[Steps forward, turns towards the map, and points to the spot where Henderson creek empties into the inlet]* (E).

Figure 1. An environmental scientist explaining the concept of "watershed" uses iconic gesture to convey the shape of the terrain, and the trajectories of rainfall, runoff, and streamflow. Switching from the generic to the specific, she then uses deictic gesture to pinpoint the map location of a specific watershed. (From Roth, 2004).

or sequence of actions or motions that unfold in space (Roth, 2000). Finally, gestures are well suited to convey continuity or continuous change or covariation, even in some situations where language might favor making categorical distinctions (Roth and Bowen, 2000). For example, where language would categorize a terrain into a "hill" and adjacent "valley," an iconic gesture would permit a continuous sweep from high to low.

For scientists at the frontiers of human understanding or for science students at the boundaries of their own understanding, gestures may help communicate about, and think about, topics for which no vocabulary is yet available (Roth, 2002). Both science students and professional scientists begin their quest to understand and explain novel scientific phenomena with what Roth and Lawless (2002) call "muddle talk," accompanied by abundant deictic and iconic gestures in the presence of scientific materials (e.g., data, samples, or experimental apparatus). As they become more familiar with the phenomena under study, they either invent (in the case of scientists) or learn (in the case of students) an appropriate scientific vocabulary, and gradually their use of gestures decreases. During the "muddle talk" phase, use of deictic gestures and words (e.g., "this", "it", "that") enables problem solving to progress without the need to find or invent the right word (Roth, 2000). Thus use of gesture preserves cognitive capacity (Goldin-Meadow, et al., 2001) for puzzling about the novel phenomena at hand.

Finally, there are some circumstances under which gestures are thought to help students bring forth and make visible ideas and knowledge that might otherwise remain unavailable to their conscious selves as well as to their conversation partners. Gesturing makes it easier for students to bring forth spatial ideas, examine them visually, and compare competing hypotheses: "it could either be shaped like this, or like this." Forming the idea into a gesture allows the gesturer to examine his or her spatial hypothesis not only visually, but also via proprioceptive feedback (Roth, 2000), that is, information derived from sensory receptors in the joints, tendons, and muscles. Because gestures are physically enacted with the body, they are considered to be a powerful means of surfacing and conveying so-called "embodied knowledge," knowledge acquired by interacting with the world and acting upon it (Lozano and Tversky, 2006). Geoscience examples of embodied knowledge include knowledge of the relative location of rock units acquired by walking through the field area, knowledge of dip angle of a rock layer acquired by placing a hand on the rock surface, and knowledge of morphological differences among fossils acquired by handling the fossils.

ANALYSIS OF GESTURES IN GEOSCIENCE

We report two analyses from the gesture literature of instructors' use of gesture while explaining geoscience-related skills and concepts, and then draw on our own ongoing research for examples of students' use of gesture.

Instructors' Use of Gesture - Roth (Roth and Lawless, 2002; Roth, 2004) analyzes an environmental scientist's use of gestures while explaining the unfamiliar concept of "watershed" in a seventh-grade classroom (Figure 1). The speaker first uses her arms to enact the motion of falling rain, and then the flow of water from higher points to lower points of the terrain. Her hands then converge downward to show water funneling into a stream, and wiggle to enact meandering. Finally she uses a pointing gesture to connect the just-enacted watershed concept to its representation on the map. This single example illustrates gesture's power to convey shape, motions that unfold in space, and position (Roth, 2000).

Goodwin (1994) uses an archeology field exercise to document the importance of pointing gestures. A student is making a profile of soil horizons exposed in a trench wall. When the professor realizes that the student is measuring at an incorrect location, she first tries a

A

Time: 05:26
Well, when we were going through *[Looks at map]* on these ones *[Points to outcrops 1 and 2]* the red [rock layer] was *[Holds up his left hand at shoulder height; dip and strike of left hand approximately parallels dip and strike of outcrops 1 and 2]*

Time: 05:27
and the yellow [rock layer] was like this *[Places right hand overlapping the left hand]*…

B

Time: 08:41
…The gradient here is definitely more steep *[Moves finger over the steep side of the asymmetric concave round model]*

Time: 08:43
than over here *[Moves finger over the shallow side of the asymmetric concave round model]*.

Time: 08:45
I felt like some of them over there *[Points to outcrops behind him]* (Referring to outcrops 4,5, and 7 in the field)

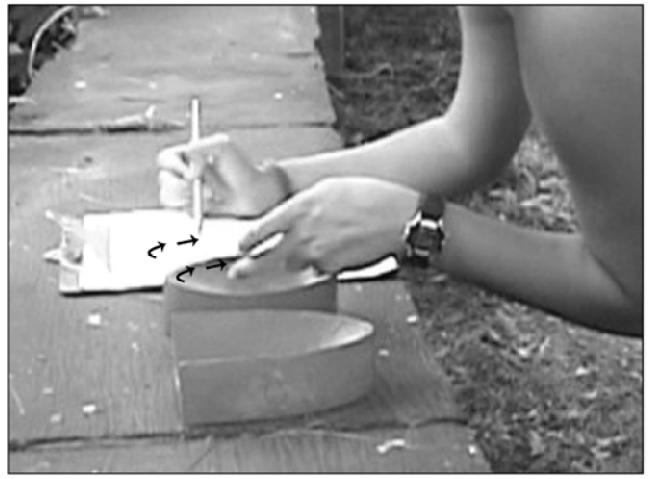
Time: 08:49
the red part was *[Gestures a steep angle into the model]* definitely very much at an incline,

Time: 08:52
whereas over here *[Points to outcrops 1,2, and 3 in the field area]* it wasn't so much. So that is why I picked this one *[Touches asymmetric concave round model]* over this one *[Touches symmetric concave round model]*.

Note: Times are minutes:seconds since experimenter asked participant to choose model.

Figure 2. (A): This student uses iconic gestures to convey his observations about stratigraphy, dip angle and strike direction of the outcrops. These gestures are environmentally-grounded (Goodwin, 2007); the dip and strike of the hands parallel the dip and strike of the actual outcrops. (B): The student then uses deictic touch to indicate the asymmetric sides of his preferred scale model and deictic pointing to indicate corresponding outcrops in the field.

Time: 03:47
[With pencil in right hand points to the spot on the map where she has recorded outcrop #1. With her left thumb touches a point on the model that she thinks may be analogous]... (Action repeated for outcrops 2 and 3).



Time: 03:55
[With pencil in right hand points to the spot on the map where she has recorded outcrop #4. With her left finger touches a point on the model that she thinks may be analogous]... (Action repeated for outcrops 5-8).

Figure 3. Some gestures seem to be exclusively for the benefit of the gesturer. This participant uses synchronized hand motions on the map (right hand) and the model (left hand) to keep track of the correspondence between map and model. She does not speak, and does not look at the experimenter.

verbal correction: measure "from you to about ninety." When this is ineffective, the professor shifts to a combination of words and gestures: she points to the place that should be measured and simultaneously states that the student should measure the coordinates where "it stops being fairly flat." According to Goodwin's (1994, 2003, 2007) interpretation of this and similar student-teacher interactions in the observed field school, pointing gestures allow the novice to learn to see features in the real world that are important to her intended profession, allow the expert to assess how well the novice has mastered the technique of seeing features of importance and inferring causative processes, and allow the expert and novice to come to an agreement about the correspondence between something on the map and something in the represented space.

Students' Use of Gesture - In our own research, we have observed abundant evidence of students using gestures as they struggle to understand and explain a geological puzzle. In our study (Kastens, Ishikawa and Liben, 2006), participants observe and takes notes on eight artificial outcrops constructed on the Lamont-Doherty campus, then select from an array of fourteen 3-D scale models to indicate which they think could be the shape of a "structure" formed by the "layered rocks" in the eight outcrops. Participants are videotaped as they make their selection and explain why they did not choose the other models.

The students in our study frequently use deictic gestures to indicate a feature on their notes, a model or group of models, a real-world direction, or the outcrops in that real-world direction. For example, the participant in figure 2 uses deictic touch to indicate the more steeply and less steeply-dipping portions of his selected scale model (times 08:41 and 08:43), and then points in front of him (time 08:52) and over his shoulder (time 08:45) to indicate the location of specific outcrops that he considers to correspond to the indicated portions of the model. In cases such as figure 2, the deictic words and gestures used by the students in our study do not seem to us to be inferior stop-gap measures used because they do not yet have the appropriate vocabulary. Rather, a deictic gesture seems to be the least ambiguous form of expression available to convey specifically which feature is being referenced.

Our participants frequently use iconic gestures to depict attributes of an observed outcrop, a specific model, or a group of models. In figure 2, the student's two hands (time 05:27) convey three different observations: the strike direction, dip angle, and stratigraphy of the pointed-to outcrops. Students also use iconic gestures to convey interpretation or hypothesis. To indicate their interpretation of the structure as a synform, students typically cup one hand upwards or sweep two hands symmetrically through the air in a U-shape or bowl shape.

Mismatch between gesture and accompanying speech has been studied extensively, in part because such mismatches are thought to be an indicator that the speaker is in a transitional state with respect to understanding the topic at hand (Church and Goldin-Meadow, 1986; Goldin-Meadow, et al., 1993; Roth 2004) or is considering multiple options or hypotheses (Garber and Goldin-Meadow, 2002). Geological examples from our data set include a student who says "concave" while her deictic gesture sweeps across the group of convex models, and says "dipping towards" while gesturing an upward slanting motion.

The focus in the gesture literature has been on use of gestures to communicate from one person to another. But we also observe gestures that appear to be exclusively for the benefit of the gesturer. In figure 3, the participant uses her right hand to slide her pencil point methodically across her map, re-enacting (Tversky and Lozano, 2006) the recent trajectory of her body as it walked from outcrop to outcrop around the field area. Simultaneously she slides her left hand across a candidate scale model to spots that she thinks might correspond to each of the eight outcrop locations. She does not look at the experimenter and does not speak aloud. The role of these gestures seems to be to organize her own thoughts, rather than to communicate to the experimenter. We might consider that the gesturer is communicating to herself (Heiser, et al., 2004), just as some people talk to themselves when puzzling through complicated tasks. Eye-gaze towards the gesture rather than towards the listener, gestures that trace a pathway, and gestures during verbal silence, are considered by Crowder (1993) to be diagnostic of students who are actively engaged in interpretive "sense-making," as contrasted with students who are merely describing something they have learned or figured out previously.

IMPLICATIONS OF GESTURE RESEARCH FOR GEOSCIENCE EDUCATORS

Although gesture research specific to geoscience is in its infancy, we can begin to identify ways in which geoscience educators can use gesture to better communicate their own ideas and understand their students' ideas:

Use of Gestures by Instructors -

- Research suggests that students learn better from gesture-enriched discourse. Instructors should use or continue to use deictic gestures (pointing) to draw students' attention to salient features on a graph, map, drawing, sample, outcrop, or model, during lectures, labs, field trips and conversation with students.
- Strive to avoid discrepancies between gesture and speech. In an analysis of students' understanding of a semester's worth of ecology lectures, Roth and Bowen (2000) found that failures to understand clustered at "decalages"--points in the discourse where the instructor's speech and gestures did not agree in timing, topology or internal structure. When McNeill, et al. (1994) introduced intentional verbal-gesture mismatches into narratives, they found that viewers misremembered those parts of the narrative, even to the point of making up wholly new scenarios that did not exist in the original narrative.
- In geosciences, where spatial thinking is such a dominate aspect of what students must learn (Chadwick, 1978; Kastens and Ishikawa, 2006), instructors should make ample use of iconic gestures to indicate shape, position, orientation, relative size, and trajectories through space. Observing iconic gestures can help students build mental models of 3-D structures and objects, and 4-D processes. Coordinated use of iconic gesture and speech can help students link spatial concepts with the appropriate professional vocabulary.
- Use gestures to enact desired actions when explaining procedures. Although most of the gesture work in science education research concerns conceptual understanding, the success of Tversky's participants (Lozano and Tversky, 2006; Tversky and Lozano, 2006) in using gesture to explain furniture assembly suggests that using gestures to enact desired actions would be beneficial in explaining scientific procedures as well.
- Model good use of gestures in small group interactions. Cook and Goldin-Meadow (2006) and Roth (2004) report that students tend to adopt the gesturing behavior that they see their instructors using during small group or individual interactions.
- Make sure students can see your gestures. Don't lecture in a darkened lecture hall. Don't stand behind the students when you explain. Don't suppress your natural gestures in an effort to look more "cultivated" (Kendon, 1997) or "professional."

Use of Gestures by Students -

- Attend to students' gestures: Educators should pay attention to their students' gestures when they are attempting to communicate a concept, especially when they are struggling for words. Research suggests that both scientists and science students tend to express emerging concepts in gestures before words.
- Attend to gesture-word mismatch. Some researchers (Goldin-Meadow, et al. 1993; Roth 2004) consider that mismatch between speech and gestures is an indicator of students' readiness to learn, an indication that they are in an unstable transitional state where they can move forward to a more correct stable understanding with appropriate instruction. In one-on-one teaching situations, experienced teachers intuitively pick up on students' increased production of verbal-gesture mismatches, and modify their instruction accordingly (Goldin-Meadow and Singer, 2003).
- Create situations that foster student gesturing. After reading this far, instructors might be tempted to simply ask, or even require, their students to gesture when explaining. When this has been tried with children, it has resulted in neither significantly increased gestures nor better problem-solving (Cook and Goldin-Meadow, 2006), perhaps because gesturing is difficult to put under conscious control. Instead, educators can establish learning situations in which student gestures are likely to emerge spontaneously. Roth (2007) reports that constructive gesturing emerges when students discuss science in small groups in the presence of materials, including inscriptions, apparatus, or artifacts. "Inscriptions" for geoscience education would include graphs, maps, images, or diagrams; "apparatus" would include laboratory equipment or physical models; "artifacts" would include objects from nature such as fossils, rock, or minerals.

DIRECTIONS FOR FUTURE RESEARCH

Many fruitful research directions remain to be explored concerning use of gestures by (geo)science students, instructors and scientists. Some questions:

- How can gestures support the teaching and learning of scientific skills and procedures (as contrasted with scientific concepts)? Examples include field skills such as measuring dip and strike, laboratory procedures such as sample preparation, and data analysis skills such as use of GIS software.
- Does gesture support (or perhaps inhibit) students' development of a sense of the scale of Earth phenomena? Tretter, et al. (2006) found that peoples'

understanding of the size of objects is anchored at the scale of their own bodies, and their ability to estimate both the relative and absolute size of objects deteriorates progressively as the scale becomes larger or smaller than a human body. If an instructor spreads his or her arms wide to convey through gesture the vastness of the solar system, do students carry away an enhanced sense of that vastness? Or does the gesture merely anchor the perceived scale of the described phenomenon more tightly to humans' default measurement tool, the human body, leaving a muddled perception that the universe is one armspan across?

- Geoscientists use arcane spatial representations to illuminate and communicate specialized information, for example, "beachball" symbols for earthquake focal mechanisms, Mohr's circle for stress and strain, and Miller indices for crystal faces. To understand papers on these topics, it is essential to understand these representations--but to understand the representations, the learner must first understand the phenomenon represented. Can use of gestures coupled with such representations break into this vicious cycle?
- Kali and Orion (1996) documented that students who had the most difficulty interpreting geological block diagrams suffered from a specific failure mode: non-penetrative errors, in which they considered only the surface of the model. Can gestures help students envision slicing into the interior of a three dimensional volume?
- As distance learning becomes more common, what information is lost if instructor and student are no longer able to see each others' gestures? Does video adequately convey instructors' iconic gestures concerning 3-D structures and processes, or is it important for learners to observe such iconic gestures in 3-D with their binocular vision?

CONCLUSIONS

Our review of the literature on gesture, plus the actions of the participants in our own study, have persuaded us that gestures are important to both learners and experts as they think about and communicate about the kind of spatially-complex structures and processes that are so common in geosciences. The field of study is sufficiently advanced that we have been able to identify promising strategies by which educators can use gesture to communicate with their students more effectively, to better understand their students' ideas, and to identify teachable moments. The use of gesture in geoscience remains a fruitful field for research, both to help cognitive scientists understand more about the use of representation in cognition, and to help geoscience educators teach more effectively.

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