Research Methodologies 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 when they talk—during informal conversations with friends and colleagues or scientific discussions with peers. A teacher gestures when explaining a scientific phenomenon to a group of students. So do students who are working 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 are not able to 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, touch briefly on 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, participants were asked to assemble a TV cart using a photograph as a guide (Lozano and Tversky, 2006). After assembling the cart, participants were divided into three groups. Individuals in the control group simply assembled the TV cart one more time. Individuals in the other two groups were asked to make a video explaining how to assemble the TV cart. Of these, one group was allowed to both speak and gesture as they made the video; the other group was told that they were making the video for non-English speakers and thus could use only gestures and actions, no speech. 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, who in turn outperformed the control group. 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 answer 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?

Mime and gesture, as techniques for purposefully communicating a remembered event, are thought to extend back at least 1.5 m.y. in evolutionary history, to Homo erectus (Kaput and Shaffer, 2002). That gesturing is still universally practiced, and was supplemented rather than supplanted by spoken language, aligns with the idea that gestures benefit people. But what exactly is the benefit? *Why* are gestures useful?

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: "Deictic gestures" indicate entities, objects, direction, or other phenomena within the conversational space, usually by pointing. "Iconic gestures" resemble some aspect of the thing 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 conversation 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 spatial dimensions (Roth, 2000), they can show, rather than tell, the recipient about attributes of three-dimensional 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, 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 without the need to imply that there is a boundary where the "hill" ends and the "valley" begins.

In the case of a person who is struggling to understand and communicate a new idea, gesture is thought to take on additional roles. In the realm of science and science education, Roth (2000) reports a high incidence of gestures when individuals are dealing with unfamiliar situations, whether those individuals are scientists at the frontiers of human understanding, or science students at the boundaries of their own understanding. In such circumstances, gestures may help people communicate about, and think about, topics for which no vocabulary is yet available. Both science students and professional scientists begin their quest to understand and explain novel scientific phenomenon with what Roth and Lawless (2002) call "muddle talk," accompanied by abundant deictic and iconic gestures in the presence of scientific materials (i.e. data representations, 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. Roth (2000) considers that during the "muddle talk" phase, deictic gestures and words (i.e. "this", "it", "that") allow people to express themselves by unloading aspects of cognition onto the environment; speakers need not derail their efforts to understand the unfamiliar by wasting mental effort on finding or inventing the right word. Similarly, Roth (2000) considers that many iconic gestures are easier to formulate and execute than the words they are to be integrated with. 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), i.e. 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), for example, how to turn the wrench to tighten the bolts of the TV cart. Geoscience examples of embodied knowledge would include an understanding of the scale and relative location of features in one's field area acquired by walking repeatedly through the area, knowledge of dip angle of a rock layer acquired by placing one's hand on the rock surface, and knowledge about morphological differences among different fossils acquired by handling and examining the actual fossils.

Analysis of Gestures in Geoscience

There has been almost no explicit study of the role of gestures in geoscience or geoscience education. We have found two analyses in the gesture literature of instructors' use of gesture while explaining geoscience-related skills and concepts: one from a field setting and one from a classroom lecture (figures 1 and 2). After presenting these two examples, we will draw on our own ongoing work for examples of students' use of gestures during geoscience discourse.

Instructors' Use of Gesture:

Goodwin (1994) uses an archeology field exercise to document the importance of pointing gestures. The student in figure 1 has been given the task of measuring the coordinates of soil layers in a trench, to assist her teacher in creating a soil profile. When the teacher realizes that the student is measuring at an incorrect location, she first tries a verbal correction: measure "from you to about ninety." When this is ineffective, the teacher 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." In this example, neither gesture nor speech alone can adequately convey the situation. 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.

Roth (Roth and Lawless, 2002; Roth, 2007) analyzes an environmental scientist's use of gestures while explaining the unfamiliar concept of "watershed" to a seventh-grade class (figure 2). 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 (figure 2). In this example, the speaker uses gesture to convey the shape of the terrain, and the trajectories of rainfall, runoff, and streamflow. Switching from the generic to the specific, she uses deictic gesture to pinpoint the map location of a specific watershed.   This single example illustrates gesture's power to convey shape, motions that unfold in space, and position (Roth, 2000).

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, orient the selected scale model to align with the full-scale structure, and explain why they did not choose the other models.

The students in our study 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. In many cases, deictic gestures are accompanied with verbal indexical terms such as “this”, “that”, or “there.” For example, the participant in figure 3 uses deictic touch to indicate the more steeply and less steeply-dipping portions of his selected scale model (times 8:41 and 8:43), and then points in front of him (time 8:52) and over his shoulder (time 8:45) to indicate the location of specific outcrops or groups of outcrops.

Our participants' deictic gestures and index terms serve to focus the attention of the participant's conversational partner onto the feature or attribute considered salient by the participant, in the manner discussed by Roth and Lawless (2002) and Lozano and Tversky (2006). These gestures also couple the student's speech (e.g. "more steep," "very much at an incline") to the associated feature in the environment, in the manner discussed by Goodwin (2007). In general, the deictic words and gestures used by the students in our study do not seem, in our estimation, to be inferior stop-gap measures used because they do not yet have the appropriate vocabulary. On the contrary, because all representations, including words, are imperfect or incomplete portrayals of the represented phenomena (e.g. Goodman, 1976), using a deictic gesture and term seems to us to be the most precise, least ambiguous form of expression that a person can use to convey specifically which feature is being referenced in a situation in which the objects or processes under discussion are present in the conversational space.

Participants frequently use iconic gestures while discussing attributes of an observed outcrop, a specific model, a group of models, or a hypothesized structure. In figure 3A, the students' two hands convey three different observations: the strike direction, dip angle, and stratigraphy of the pointed-to outcrops. Figure 4 shows a student using iconic gestures to convey interpretation rather than observation: her interpretation that the structure formed by combining the eight outcrops is convex. Interestingly, this student's mental model is incorrect (the correct structure is concave rather than convex) but her gesture-supported explanation of her mental model is clear. Note that the participants' use of "this" in her sentence satisfies the requirement of English syntax but the content of her communication is conveyed by her gesture, not by her word. The gesture has become, in effect, a component of the sentence.

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 2007) or is considering multiple options or hypotheses (Garber and Goldin-Meadow, 2002). A geological example of this phenomenon is shown in figure 5. This student has studied geology, although not recently, and uses geological terminology in her explanation. She speaks the words "dipping towards" while gesturing an upward slanting motion (figure 5, 01:28). An expert, in contrast, would use the term "dipping towards" to refer only to the down dip direction. From her earlier education, she has retained the concept that the direction and steepness of inclined layered rocks are important attributes, and her gesture reflects this understanding, but her usage differs from the experts' usage. The same participant says "concave" while her deictic gesture sweeps across the group of convex models (figure 5, 00:08).

The focus in the gesture literature has been on use of gestures to communicate from one person to another. But we also observe gestures, or gesture-like actions, that appear to be exclusively for the benefit of the gesturer, gestures that are not accompanied by verbal utterances, and do not involve communication with the experimenter. Consider for instance, figure 6, where the student seems to be using gesture to keep track of the correspondence between map and model. With her right hand the participant slides her pencil point methodically across her map from the point where she has noted the location of outcrop #1 to #2, to each of her eight mapped outcrop locations. Her pencil and finger re-enact (Tversky and Lozano, in press) 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. As the participant compares outcrop locations, she does not look at the experimenter and does not speak aloud. The role of these gestures seems to be to organize or keep track of 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 some 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 a 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. When switching between cues (for example, from a diagram or a photograph to gestures that are not related to the diagram or photograph), instructors can use body movement to signal change of cues and refocus attention of the listener.

- Strive to *avoid discrepancies between gesture and speech*. In an analysis of students' understanding of a semesters' worth of ecology lectures, Roth and Bowen (2000) found that failures to understand clustered at "decalages"--points in the discourse where the instructors' 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.[1]
- 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, in press) 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 (2007) report that students tend to adopt the gesturing behavior that they see their instructors using during small group or individual interactions. There is no need to explicitly discuss the fact that you are gesturing;

[1] There is some evidence, that under some circumstances, students may benefit from an instructor's verbal-gesture mismatch, as when an elementary school math teacher presents a mathematical principle in speech and a complementary algorithm in gesture (Singer and Goldin-Meadow, 2005). But such studies deal with very specific pedagogical circumstances, far removed from geoscience, and we lack the knowledge base to identify circumstances in which a geoscience instructor's verbal-gesture mismatch might be helpful rather than harmful.

students will incorporate gestures into their own communicative repertoire unconsciously.

- *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. Gestures are not just random hand movements, but communicate important information about students' understandings or misunderstandings. Special attention should be given to gestures when students are struggling for words, because 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 2007) 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. Table 1 summarizes Roth's (2007) interpretation of the meaning of gesture-verbal mismatch and implications for teaching. 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. In the context of geoscience instruction, "inscriptions" 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 geoscientists' discourse or papers on these topics, it is necessary to understand these representations--but to understand the representations, the learner needs to 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 the 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 and learning scientists understand more about the use of representation in cognition, and to help geoscience educators find more effective ways to teach students in their discipline.

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Table 1

Students' word-gesture mismatches as a source of insight for science educators

(based on Roth, 2007)

Instructor's Observation	Roth's interpretation of meaning	Roth's recommended action
Words & gestures are consistent but incorrect.	Students are far from understanding.	Provide more time to explore and discuss materials.
Words & gestures are inconsistent; gestures are more nearly correct.	Normal. Students are moving towards understanding; ability to explain verbally lags.	Teachable moment: pose challenges, ask questions, ask student to elaborate, explain, describe.
Lag between gestures and words (first explain correctly with gesture, then add words).	Normal. Lag should decrease over time, indicating better understanding.	Only after the lag has decreased would Roth move towards having them write about their experiment.

Figure Captions

Figure 1: Deictic gestures can be effective at calling attention of the listener to a feature of interest. (A) A professor (in foreground) in an archeological field school uses deictic gestures to focus the attention of a student (wearing hat) at the point where measurements should be taken to correctly map soil horizons in a trench (From Goodwin, 1994; permission requested). (B): Profile map of the soil layers, the product of the field exercise in (A) (From Goodwin, 1994; permission requested).

Figure 2: Iconic gestures can be useful in explaining unfamiliar spatial concepts. In this example an environmental scientist enacts rain falling, river meandering, and water funneling into an inlet to explain the term "watershed" to a 7^{th} grade class unfamiliar with this concept (From Roth, 2007; permission requested).

Figure 3: Student use of deictic and iconic gestures. (A): The participant points towards outcrops #1 and 2 in the field to call experimenter's attention to the outcrops, and then uses iconic gestures to convey his observations about stratigraphy (two rock layers), dip angle and strike direction of the outcrops. (B): Participant points to asymmetric sides of a concave round model and uses deictic gestures to show corresponding outcrops in the field.

Figure 4: Student use of iconic gesture to convey interpretation. The participant models one set of layers with the motion of her right hand, a second set of layers with the motion of her left hand, and then uses both hands symmetrically to gesture a convex shape that she hypothesizes could be formed by combining observations from all the outcrops.

Figure 5: Example of mismatch between gesture and words. (A): The participant uses the words "concave models" while pointing to "convex" models. (B): The participant uses the phrase "dipping towards" to refer to both updip and downdip directions, whereas a geologist would use the phrase "dipping towards" only when referring to the "downdip" direction.

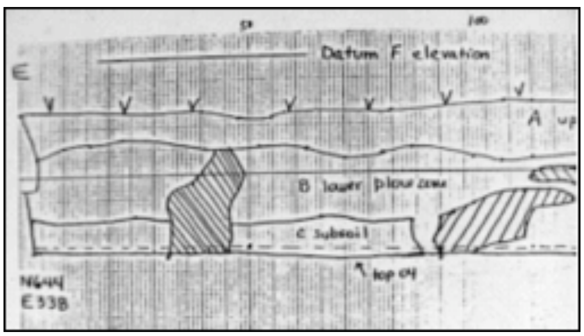
Figure 6: Some gestures seem to be exclusively for the benefit of the gesturer. In this example the participant uses her hand motions on the map (right hand) and the model (left hand) to organize her thoughts, without communicating to the experimenter.

Figures

Figure 1

A

B



Professor: Give me the ground surface over here to about ninety.

Student: *[Moves both her body and the tape measure to the right, stopping near the 90 mark on the upper ruler]*.

Professor: No-No- Not at ninety. From you to about ninety.

Student: Oh.

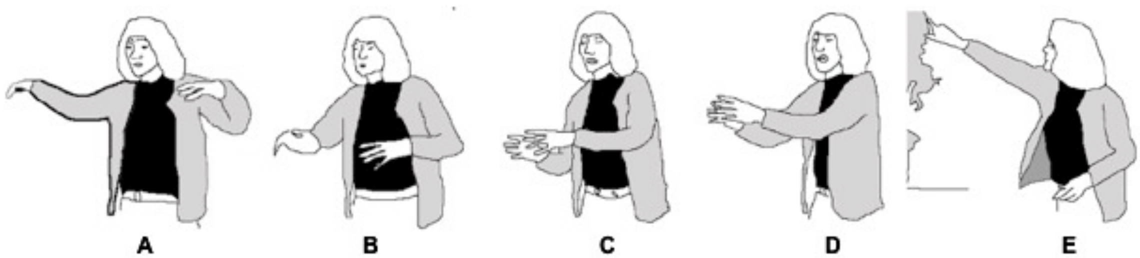
Professor: Wherever there's a change in the slope.

Student: Mm kay *[Moves her tape measure far to the right]*.

Professor: See so if it's fairly flat *[Moves into the space student is attending to and points to one place that should be measured* (See photo A)*]*. I'll need one where it stops being fairly flat.

Professor: Like right there. Then I will need one there [*Points to additional places for measurement*].

Figure 2



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 and turns towards the map the spot where Henderson creek sheds into the inlet]* (E).

Figure 3

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 *[Held 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 pick 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 4

Time: 02:16
Which means that layers of rock are going to be like this *[Moves the right hand downward/outward at an angle; repeats gesture twice]*.

Time: 02:21
On the other side, the outcrop is facing in like this *[Right hand angled at 45 degrees from the horizontal with palm facing down and to her left]…*

Time: 02:22
and the layers of rocks are like this *[Left hand moving downward/outward]*.

Time: 02:24
Then together that forms a convex shape *[Moves both hands from center of chest downward and outward symmetrically]*.

Figure 5

A

Time: 00:08
I don't feel like any of these concave ones *[Indicating to convex models]*. So, not those *[Moves hand over all the convex models in the foreground of the photograph]*.

*********************************** **

B

Time: 00:53
…it wasn't dipping towards a point in the air *[Gestures symmetrically with two hands; hands move diagonally upwards and towards each other to meet at a point in the air]*.

Time: 00:55
It was dipping towards a point in the ground [*Gestures symmetrically with two hands; hands move diagonally downward and towards each other]*.

Figure 6

Time: 03:47
[With pencil in right hand points to the spot on the map where she has recorded outcrop #1. With her thumb touches a point on the model that 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 finger touches a point on the model that may be analogous]...

(Action repeated for outcrops 5-8).