# Representing Space: Exploring the Relationship between Gesturing and Geoscience Understanding in Children

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**Abstract.** Learning in science requires the ability to think spatially and gesturing has been shown to ground students' understanding of spatial relationships. However, despite theoretical reasons to hypothesize a relation between the use of gesture and science understanding, few studies provide strong empirical evidence of a link between these factors. In the present study, we explored whether spontaneous use of gesture is associated with children's understanding of spatially intensive geoscience concepts. Eight- to sixteen-year-old children ($N$ = 27, $M$ = 11.79 yrs) were provided instruction about the causal mechanisms of mountain and volcano formation and were then interviewed for their understanding of these mechanisms. Analyses of children's responses to the interview questions revealed significant positive correlations between children's knowledge of geoscience and the spontaneous production of iconic, content-relevant gestures. These findings help to empirically establish a long hypothesized link between gesture and science understanding, and suggest that gesturing may facilitate understanding of difficult spatial science concepts.

**Keywords:** Gesture, Spatial Reasoning, Geoscience Education, Children

## 1 Introduction

Scientists often gesture when they reason about and explain science concepts (Goodwin, 2007; Kastens, Liben, & Agrawal, 2006; Resnick, Atit, Goksun, & Shipley, 2011). This phenomenon is not surprising, given that gesturing can facilitate spatial reasoning (Alibali, 2005; Goldin-Meadow, 2000) and spatial reasoning is an important aspect of learning and communicating scientific concepts. For instance, recent studies have documented empirical links between spatial reasoning abilities and understanding in scientific disciplines (Kozhevnikov, Motes, & Hegarty, 2007; Coleman & Gotch, 1998; Hegarty, Crookes, Dara-Abrams, & Shipley, 2008; Orion, Ben-Chaim, & Kali, 1997). Furthermore, real-world scientists commonly utilize spatial representational tools – such as models (Nersessian, 2009), diagrams (Novick, 2006), and sketching (Ainsworth, Prain, & Tytler, 2011) – along with gestures (Goodwin, 2007; Kastens, Liben, & Agrawal, 2006; Resnick, Atit, Göksun, & Shipley, 2011) to reason about scientific concepts.

Though scientists often utilize representational tools such as gesture, still relatively little is known about the relationship between novice science learners' spontaneous use of gesture during the course of science learning. Gesturing might be particularly important for novices who lack the domain knowledge and spatial reasoning abilities of highly trained scientists. The present study focuses on the use of gesture and its relation to children's understanding of elementary geoscience concepts, which is one of the most spatially intensive amongst the scientific disciplines (Hegarty, Crookes, Dara-Abrams, & Shipley, 2008; Jee et al., 2010; Kastens, Liben, & Agrawal, 2008; Liben, Kastens, & Christensen, 2011). We first review literature outlining how gesture influences spatial thought, and then we discuss the role that gestures may play in the acquisition of early geoscience concepts.

## 1.1 Gesture and Spatial Reasoning

Prior research has revealed at least three ways in which gesturing augments spatial reasoning. The first is that gesture promotes attention to spatial information (Alibali, 2005; Alibali, Spencer, Knox, & Kita, 2011; Rimè, Shiaratura, Hupet, & Ghysselinckx, 1984). For example, Sauter and colleagues showed that eight- to ten-year-old children who used gestures in communicating relations among locations tended to produce more spatial information in their speech than children who did not use gesture (Sauter, Uttal, Alman, Goldin-Meadow, & Levine, in press). In addition, children who produced gesture-speech mismatches when predicting which way a balance beam will fall – that is, their gestures reflected distance information but their speech reflected only weight information – were more likely than children who did not produce such gesture-speech mismatches to explicitly recognize the importance of both weight and distance information later on in learning (Pine, Lufkin, & Messer, 2004). Thus, recruitment of gesture can cue attention to spatial information.

Another way in which gesture can augment spatial thinking is that it can allay demands placed on working memory. De Ruiter (1998) found that speakers were more likely to gesture when they needed to convey spatial information of objects and when visual representations of those objects were unavailable. This finding was replicated with both objects that were difficult to verbally describe (e.g., patterns of lines as shapes), as well as with objects that were easily verbalized (e.g., a flower, a clock, etc; Morsella & Krauss, 2004). Taken together, these studies suggest that gesture acts as a representational tool that allows speakers to more fluently and accurately convey spatial content (Alibali, 2005; Wesp, Hess, Keutmann & Wheaton, 2001).

Finally, gesture appears to facilitate the spatial reasoning process itself. A number of studies have found that participants who spontaneously gesture during spatial tasks perform better at those tasks than individuals who do not gesture (e.g., Cook & Goldin-Meadow, 2006). Rauscher, Krauss, and Chen (1996) found that participants who were prohibited from gesturing while describing a series of action cartoons verbally produced less spatial content than participants who were allowed to gesture. Another study showed that even preschool-age children benefit from gesturing in spatial transformation tasks (Ehrlich, Levine & Goldin-Meadow, 2006; Ping, Ratliff, Hickey, & Levine, 2001).

In sum, gesturing can act as a useful representational tool for thinking about spatial information for both children and adults. Next we consider how gesture may influence students' reasoning in the highly spatial domain of geoscience.

## 1.2 Gesture and Geoscience Learning

Prior research suggests that expert geoscientists frequently utilize gesture during the course of scientific reasoning. For example, Kastens, Liben, and Agrawal (2008a) documented geoscientists' use of gesture as they attempted to integrate 3-D models of geological structures with their observations of artificial rock outcrops. This investigation revealed that geoscientists repeatedly made deictic (i.e., pointing) and iconic (i.e., hand movements intended to represent concrete entities) gestures to refer to and describe geological phenomena. Similar findings are reported when structural geology experts were asked to read and explain a geologic map (Resnick, Atit, Goksun, & Shipley, 2011)

To our knowledge, however, only a handful of studies have addressed whether novice geoscience learners spontaneously utilize gesture. One case study followed a group of three 6th-grade students in depth over the course of a unit on plate tectonics (Singer, Radinksy, & Goldman, 2008) and found that students used gestures to create a shared representation, sometimes correcting or modifying their peers' gestures during the course of learning. In addition, Liben, Christensen, and Kastens (2010) asked university students to complete tasks related to the geologic concepts of strike and dip (i.e., of methods of describing the orientation of tilted layers of rock in three-dimensional space) and found that students who had no prior experience with the geologic terms were the only group of participants who gestured during the reading task.

Though these studies provide valuable process descriptions of how experts and novices incorporate gestures when learning geoscience, the nature of the relationship between gesturing and geoscience learning is still unclear: do novice geoscience learners gesture more frequently? Or do they gesture less and simply make better use of gestures that they produce? In this paper, we report an analysis of novice learners' gesturing in a laboratory investigation.

### 1.3 The Present Study

The primary aims of the present study were to explore 1) whether there is a relationship between gesturing and children's geoscience understanding, and 2) to document the nature of this relationship. This research was conducted within the context of teaching children about an important concept in elementary geoscience education: plate tectonics. Plate tectonics is the study of how the earth's plates are driven and shaped by geological forces that keep them in constant motion, which is a fundamental mechanism involved in the formation of volcanoes and mountains. Despite its importance, however, children have been shown to exhibit a variety of misconceptions in this domain (Gobert, 2004; Matlen, Vosniadou, Jee, & Ptouchkina, 2011; May, Hammer, & Roy, 2006).

Given that expert scientists commonly gesture, and that gesturing facilitates spatial reasoning in cognitive tasks (e.g., Alibali et al., 2011; Cook & Goldin-Meadow, 2006), we hypothesized that children who spontaneously produce gestures would exhibit better understanding of geoscience overall than children who do not use gestures.

## 2 Method

The study reported in the present paper was part of a larger experiment that investigated the use of instructional text and graphics on the teaching of geoscience concepts. Here, we report the methods and results relevant to our investigation of gesturing and geoscience learning.

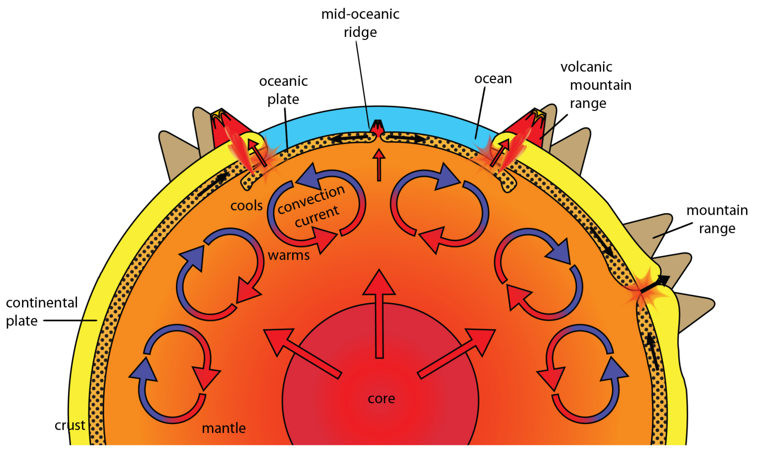
### 2.1 Participants

Participants were 27 eight- to sixteen-year-old children (*M* = 11.79, *SD* = 2.29, 14 girls, 13 boys) recruited from the Pittsburgh area. We recruited children from this age range to represent a broad sample of K – 12 students.

### 2.2 Materials and Procedure

All children were tested individually in a laboratory at Carnegie Mellon University. The experiment was comprised of two phases – the instruction and interview phases – that are described in detail below.

**Instruction Phase.** Children were asked to view instruction on a computer screen that consisted of both pictures and words that pertained to the topic of plate tectonics. Children were allowed to take as long as they needed to read and study the instruction. The instructional material comprised 15 slides, each slide included a short instructional text and a static picture designed to illustrate the geological phenomena mentioned in the text[1]. An example of one of the slides is provided in Figure 1[2].



Convection currents are the forces that cause the Earth's surface to move and change. Sections of the Earth's crust that rest on top of the mantle, called 'plates,' move with the convection currents below them, and are the cause of volcanoes, mountains, and earthquakes on Earth.

**Fig. 1.** An example slide from the instruction.

The instruction covered three important boundary types: 1) oceanic – oceanic divergent boundaries where mid-oceanic ridges form, 2) continental – continental convergent boundaries where mountain ranges form, and 3) continental – oceanic convergent boundaries where volcanic mountain chains form.

After reading the instruction, children filled out a motivation questionnaire that consisted of six statements. Students were asked to rate, on a scale from 1 – 7, how much they agreed with each of the statements, with 7 meaning "strongly agree" and 1 meaning "strongly disagree". The statements pertained to the extent to which children considered plate tectonics to be 1) exciting, 2) fun, 3) important, 4) useful, 5) desirable to learn more about, and 6) desirable to take as a class at their school.

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[1] Subjects received one of three versions of the pictures: 1) an abstract version that was devoid of color, 2) a relevant concrete version that consisted of colors for relevant concepts (pictured in Figure 1), and 3) a concrete version that consisted of colors for relevant concepts as well as other non-relevant pictures, such as airplanes or clouds surrounding the Earth. No differences were found in children's interview performance, gestures produced, or motivation produced as a function of the type of pictures they were instructed with (all *p*s >.10), therefore, we collapse students' performance across these groups.

[2] This diagram is intended to be schematic in nature and is therefore simplified such that it ignores the issue of scale and conveys only very basic concepts in plate tectonics (i.e., that plate movement – caused by heat in the Earth's interior – causes Earth's geological change). The design of the diagram was based on an informal review of graphics commonly used in elementary-school science textbooks.

**Interview Phase.** During the interview phase, children were videotaped while they verbally answered questions from the experimenter about plate tectonics. Children were asked a total of ten questions in a fixed order. The first six questions pertained to concepts that children had learned about during the instruction (e.g., what causes the Earth's plates to move?). The final four questions consisted of showing children pictures of actual geological formations on Earth (e.g., the Himalayas). Then, children were provided a short description of the geological formation and were asked how they thought it formed (e.g., "*This is the Himalayan Mountain Range located in India,*" [Experimenter points to the field-photograph depicting the Himalayas] "*it is the tallest mountain range in the world. How do you think the Himalayan mountain range formed?*").

## 2.3 Scoring

To code for accuracy during the interview phase, an ideal answer was generated for each question and then broken down into individual knowledge components (henceforth referred to as "KC's"; see Koedinger, Corbett, & Perfetti, in press)[3]. For example, for the question "How do mountains form?" the associated knowledge components were 1) two continental plates, 2) collide, and 3) produced an upward force. The first and third authors coded a random selection of 25% of the videos for the presence of KC's in each child's responses. Overall, the raw inter-rater agreement was $r = .94$, kappa = .85. The first author then coded the remainder of children's responses. The score on the motivational questionnaire was the sum of the points for each question.

## 2.4 Gesture Coding

In order to analyze children's spontaneous use of gesture during the interview, we coded children's hand and arm movements into one of three categories: 1) KC-relevant gestures, 2) KC-irrelevant gestures, and 3) unrelated gestures. Both KC-relevant and KC-irrelevant gestures were "iconic" in that they referred to concrete entities (Roth & Lawless, 2002) in the domain of geoscience, where KC-relevant gestures pertained to geoscience phenomena that corresponded to a KC of a given question (e.g., a circular hand-motion to represent a convection current in response to the first question) and KC-irrelevant gestures pertained to concepts in geology, but did not correspond to any of the KC's of a given question (e.g., short, rapid movements of the hands to represent an earthquake). Unrelated gestures were either iconic gestures referring to concrete entities not related to geoscience content (e.g., a ship). The first and third authors coded a random selection of 25% of the videos for the presence of each type of gesture. On average, the raw inter-rater agreement was $r = .94$, kappa = .84. The first author then coded the remainder of the videos for the presence of each gesture type.

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[3] Knowledge components are equivalent to concepts, principles, facts, or skills.

# 3 Results

## 3.1 Correlational Analyses

In total, we identified 270 KC-relevant gestures, 160 KC-irrelevant gestures, and 56 unrelated gestures. We first conducted correlations to see if children's age, gender, and motivation scores correlated with the proportion of KC-relevant gestures produced (i.e., relative to all gestures they produced) and the proportion of KC's children correctly identified during the interview (henceforth referred to as "interview accuracy"). There were no significant correlations between children's motivation scores, gender, interview accuracy, and proportion of KC-relevant gestures produced (all *p*s > .44). However, age was significantly correlated both with interview accuracy ($r = .453$, $p < .05$) and with the proportion of KC-relevant gestures produced ($r = .446$, $p < .05$). In order to control for children's age, motivation, and gender, partial correlations were conducted for all subsequent correlational analyses.

Of primary interest to us was whether the proportion of KC-relevant gestures that children spontaneously produced relative to all gestures produced would correlate with understanding of plate tectonics. Thus, we investigated the correlation on the proportion of KC-relevant gestures children produced by their interview accuracy, which revealed a significant, positive correlation ($r = .668$, $p < .001$) (see Figure 2). There was also a significant positive correlation between interview accuracy and the raw numbers of KC-relevant gestures children produced ($r = .575$, $p < .005$).

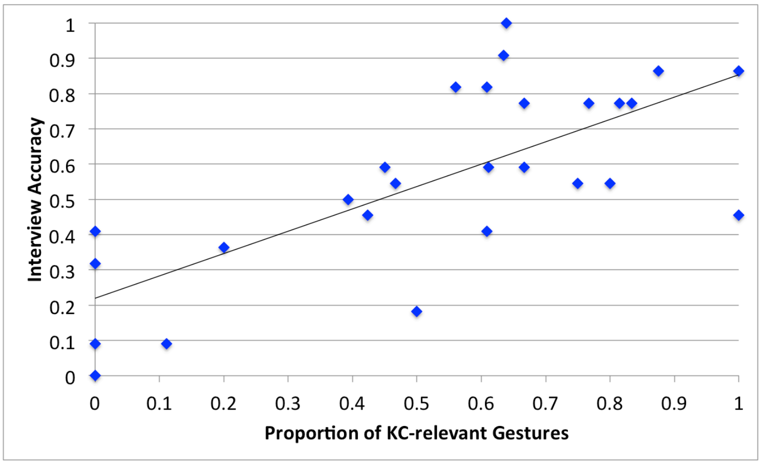

**Fig. 2.** Proportion of KC-relevant gestures produced as a function of interview accuracy.

To examine whether other types of gestures correlated with geological understanding, we computed two more correlations, one on the proportion of KC-irrelevant gestures and interview accuracy, and another on the proportion of unrelated gestures and interview accuracy. These analyses revealed no significant relationship between the proportion of unrelated gestures and interview accuracy ($p > .52$). However, there was a significant, negative correlation between the proportion of KC-irrelevant gestures and interview accuracy ($r = -.663$, $p = .001$).

### 3.2 High- vs. Low-KC-Gesturers

To further explore the robustness of the relationship between KC-relevant gestures and geology understanding, we parsed children using a median split based on the proportion of KC-relevant gestures produced (*Med* = .61). This division created two groups: a "High-KC-gesturers" group and a "Low-KC-gesturers" group (High-KC-gesturers produced a significantly higher proportion of KC-relevant gestures $M = .77$, $SD = .13$ than Low-KC-gesturers $M = .33$, $SD = .23$; $t(24) = 5.87$, $p < .001$)[4]. There were no significant differences between High- and Low-KC-gesturers with regard to their motivation scores or gender (all *p*s > .24). There was a significant difference between the ages of each group, with the High-KC-gesturers ($M = 12.78$ yrs, $SD =$ 1.89 yrs) slightly older on average than the Low-KC-gesturers ($M = 10.97$ yrs, $SD =$ 2.4 yrs; $t(24) = 2.08$, $p < .05$). Importantly, High-KC-gesturers evidenced significantly higher interview accuracy ($M = .73$, $SD = .17$) than Low-KC-gesturers ($M = .41$, $SD = .26$; $t(24) = 3.75$, $p < .001$).

Do High-KC-gesturers simply gesture more often than Low-KC-gesturers? To directly explore this possibility, we conducted an independent samples t-test on the total number of gestures (i.e., KC-relevant, KC-irrelevant, and unrelated gestures) produced by both High- and Low-KC-gesture groups. This analysis revealed no differences between the groups (for the High group $M = 18.54$, for the Low group $M =$ 18.08) $t(24) = .08$, *ns*. Additionally, to directly test whether there were differences in the types of gestures produced by High- and Low-KC-gesturers, we conducted a 2 (KC-gesturer: High vs Low) x 3 (gesture type: KC-relevant, KC-irrelevant, and unrelated) mixed ANOVA on the raw number of gestures produced, which revealed a significant effect of gesture type $F(2,48) = 19.59$, $p < .001$, qualified by a significant interaction $F(2,48) = 8.11$, $p = .001$ (see Figure 3). Post-hoc tests revealed that Low-KC-gesturers produced a significantly higher number of KC-irrelevant gestures ($M =$ 8.31, $SD = 7.51$) than High-KC-gesturers ($M = 3.23$, $SD = 3.42$); $p < .05$), that High-KC-gesturers produced significantly more KC-relevant gestures than they did KC-irrelevant or unrelated gestures (all *p*s > .005), and that Low-KC gesturers produced significantly more KC-relevant and KC-irrelevant gestures than they did unrelated gestures (all *p*s < .01).

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[4] One child never gestured and therefore was not included in this analysis.

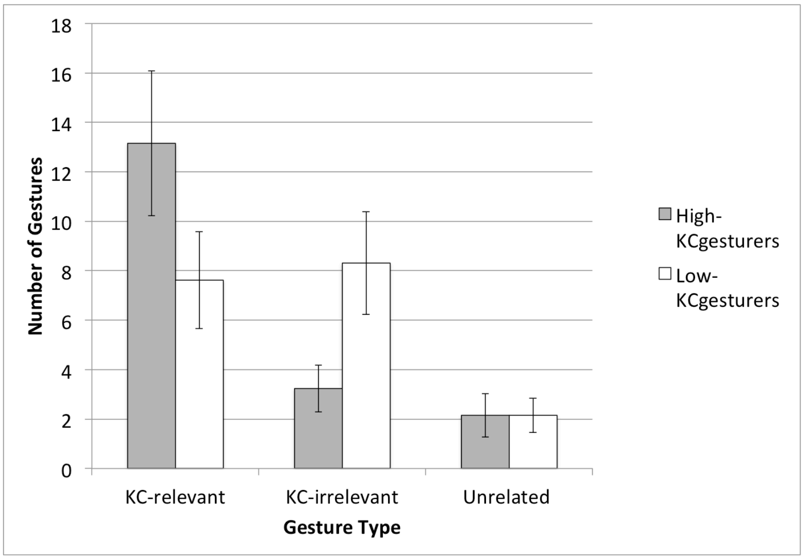

**Fig. 3.** Mean number of raw types of gestures produced as a function of whether children were categorized as High- or Low-KC-gesturers. Error bars represent standard errors of the mean.

## 4 Discussion

The primary aim of the present study was to determine whether children's gesturing was associated with their understanding of geoscience concepts. We found that students who produced a higher proportion of KC-relevant gestures were more likely to understand geoscience-related concepts, even when controlling for children's age, motivation, and gender. Moreover, both high- and low-KC-gesturers produced a similar amount of gestures overall, suggesting that it was not the *amount*, but rather, the *content* of children's gestures that predicted geoscience knowledge. This study is among the first to report a quantitative relationship between the frequency of children's gesturing and the understanding of a spatially demanding scientific concept. Our findings suggest that gesturing may even facilitate the process of learning science concepts, an insight that could have important implications for learning and instruction in science education.

However, due to the correlational nature of the present study, it is difficult to determine whether gestures caused or simply reflected geoscience understanding. Since in our task, children were asked to explain geoscience concepts to the experimenter, gesture may have assumed primarily a communicative role: those children who demonstrated better understanding of plate tectonics may have been better able to convey those concepts in gesture. Since a number of qualitative studies have shown that gesturing plays an important role in the acquisition of scientific concepts (e.g., Crowder, 1996; Roth, 2000), we surmise that children's gesturing may also have facilitated scientific understanding, but future research is needed to further examine this issue.

As the present study cannot tease apart the causal nature of gesturing and geoscience understanding, our future aim is to directly examine whether encouraging gesture causes increased geoscience understanding. Specifically, we are currently conducting a follow-up study in which we systematically compare the learning and transfer of children who are directly encouraged to gesture during the learning phase vs. those are inhibited from gesturing. If gesturing does influence understanding, we would expect the gesture group to show stronger performance - as well as more frequent use of relevant gestures – on a post-test interview, similar to the one reported in this study.

In sum, though the present study is preliminary in nature. It is the first to our knowledge to document a quantitative relationship between gesturing and geoscience understanding in children. Although this relationship is correlational, these findings raise the possibility that incorporating and directly teaching gestures within the classroom will offer support for struggling students. At minimum, our results provide an empirical basis for the future investigation of this possibility.

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