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The Role of Instructional Gesture in Learning Science Concepts in Undergraduate Students

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Abstract

Recent research has shown that hand gestures produced by both teachers and learners make underlying mechanisms and abstract symbols more concrete for learning (Goldin-Meadow, Levine, Zinchenko, Yip, Hemani, & Factor, 2012; Vallotton, Fusaro, Hayden, Decker, & Gutowski, 2015). The current study examined the effects of instructional gesture on undergraduates' learning of plate tectonics by manipulating gesture in several instructional conditions. There were three videotaped conditions in the study: *representational gesture*, *beat gesture,* and *no gesture*. It was hypothesized that instructional gesture condition would enhance the understanding of plate tectonics in undergraduate students. Results showed that while all conditions increased in learning overall, the *representation gesture* condition showed the most improvement, although it was not statistically significant. Results also showed that participants categorized as having low prior knowledge had statistically significantly higher average change scores than participants with high prior knowledge. The findings from the study are helpful for both in class and online learning. Encouraging instructors to produce representational gestures with their accompanying speech, especially with abstract topics with novice learners, will provide more support for learning.

The Role of Instructional Gesture in Learning Science Concepts in Undergraduate Students

Mathematical and scientific concepts are often difficult to learn because they are highly complex and abstract and are particularly problematic for novice learners (Hemmerich & Wiley, 2002). Abstract concepts rely on a deeper level of conceptualization, whereas concrete concepts rely on sensorial experience e.g. touch, smell and sight (Borghi, Binkofsky, Castelfranchi, Cimatti, Scorolli, & Tummolini, 2017). Science and mathematical concepts often lack perceptual information or cues to help the novice learner. In other words, many scientific phenomena occur on a scale either too large (ex. plate tectonics) or too small (ex. cell functions) to be able to be seen naturally. This can make it difficult for novice learners to understand the underlying mechanisms of scientific phenomena without the relevant perceptual cues and information (Clark & Paivio, 1991).

Previous research has shown that learners have a better understanding of underlying mechanisms that involve both spatial/static and causal/dynamic aspects when using visual aids, including diagrams, images, maps, multimedia content, etc. (Gobert & Clement, 1999). Visual aids are beneficial in creating and observing higher-level mental representations of concepts and extend the learner's knowledge from memory recall to critical thinking about the concepts. While visual aids have been found to be useful for learning, they have some limitations. Visual aids present information all at once, making it difficult for a novice learner to fully understand the underlying movement of the spatial elements that help explain many science concepts (Gobert & Clement, 1999; Kang, Hallman, Son & Black, 2012).

Recent research has shown that hand gestures produced by both teachers and learners make underlying mechanisms and abstract symbols more concrete for learning (Goldin-Meadow, Levine, Zinchenko, Yip, Hemani, & Factor, 2012; Vallotton, Fusaro, Hayden, Decker, &

Gutowski, 2015). In math and science instructional settings, learners and teachers often use spontaneous gestures with their speech that convey spatial and dynamic elements of math and science concepts (Gobert & Clement, 1999; Rueckert, Church, Avila, & Trejo, 2017; Singer & Goldin-Meadow, 2005). Gestures, unlike most visual aids and diagrams, provide three dimensional and spatial movements that help novice learners visualize the less perceptible aspects of concepts (Goldin-Meadow, 2003; McNeil, 1992). For example, teachers spontaneously produce gesture while instructing novice learners on the concept of mathematical equivalence (e.g., 3+4+5=_+5), the teacher will sweep under the right side of the equation and then sweep under the left side of the equation, while in her accompanying speech stating, "3+4+5 = 17, and the other side must also equal 17." Here, the teacher's gesture conveys the idea that both sides of the equation must be balanced or equal, making the relational symbol of the equal sign more concrete for the novice learner (Singer & Goldin-Meadow, 2005).

At the same time, learners also spontaneously produce gestures while explaining their understanding of math and science concepts. For example, in response to a teacher's question to the class on how earthquakes are formed, a learner produces two flat hands (palms facing down) moving toward each other while saying in speech, "when both plates are moving in the same direction." Here, the learner is using gesture to show how two plates converge to form earthquakes, helping facilitate her understanding that is not complete in her speech alone **(**Singer, Radinsky, & Goldman, 2008). This example also illustrates how gestures help learners explain the movement of plates that is difficult to fully grasp in static visual aids.

Gestures are produced in a variety of contexts and across different stages in development and learning (McNeil, 1992). Common gesture types include beat gesture, point and trace gestures (deictic), and iconic gesture. Beat gestures are simple hand movements that beat to the rhythm of the speaker’s speech. They do not often convey any substantive information, but they draw attention to the individual producing the gesture, as well as help the gesturer maintain the rhythm of their accompanying speech. Deictic gesture is used to indicate objects and locations (Goldin-Meadow, 2003). Deictic gesture directs the attention of the listener to an object or space, thereby establishing joint attention between the speaker and listener on a particular object or place. For example, an instructor may point to a particular place on a map while stating the location in her accompanying speech. Iconic gesture reflects the speaker’s mental imagery and may convey visual or spatial elements or moving actions (Hostetter & Alibali, 2008). Iconic gesture conveys substantive information and the meaning is reflected in the form of the gesture. The speaker’s form and movement of the hands often bear close resemblance to the objects and their movements, accompanied by the speaker’s speech. For example, while an instructor produces two hands lying flat, palms facing downwards, moving the hands toward each other, the instructor’s accompanying speech is describing the movement of plate tectonics. Both deictic and iconic gestures are considered representational gestures, as they both convey semantic meaning. This type of gesture makes it possible for a speaker to convey both physical attributes of objects and their movements, as well as indicate nearby locations and referents. Thus, making it possible for speakers to convey causal explanations and the meaning of abstract symbols in science and math (Kang, Hallman, Son & Black, 2012).

Gesture Facilitates Learning

Representational gestures are often spontaneously produced by both instructors and learners while verbally explaining abstract and spatial concepts in science and mathematical problem-solving (Crowder, 1996; Singer & Goldin-Meadow, 2005). Moreover, producing and observing gestures in various settings have been found to promote learning in math and science

(Singer & Goldin-Meadow, 2005; Singer, Radinsky, & Goldman, 2008; Cook, Goldin-Meadow, 2006; Koumoutsakis, Church, Alibali, Singer, & Ayman-Nolley, 2016). In the current study, representational gestures were used in instruction to teach students about an abstract scientific concept, plate tectonics.

Learners often produce gestures in both classroom settings and in one-on-one tutorials when explaining mathematical problem-solving as well as their scientific reasoning (Crowder, 1996). When learners are instructed to gesture or spontaneously produce gestures (Goldin-Meadow & Singer, 2005; Roth, 2003) they are more likely to learn those concepts (Goldin-Meadow, Levine, Zinchenko, Yip, Hemani, & Factor, 2012; Vallotton, Fusaro, Hayden, Decker, & Gutowski, 2015). Cook, Mitchell, and Golden-Meadow (2008) studied the benefits of producing gesture by instructing learners to gesture while learning a new mathematical concept. Children were asked to make an addition problem, “4+9+3= 4+ ___” equal on both sides. The instructor taught using a flat palm sweeping gesture from one side to the other, and half of the children were instructed to use the same gesture themselves. They found that when children were required to gesture, they retained knowledge better than children required to use speech only during instruction.

Teacher’s gestures have also shown to promote learning in classroom settings and one-on-one tutorials (Alibali, Nathan, Wolfgram, Church, Jacobs, Martinez & Knuth, 2013; Ruekert, Church, Avila & Trejo, 2017). Both spontaneous gestures and rehearsed gestures have promoted more learning in comparison to no gestures in both math and science learning (Alibali, Nathan, Wolfgram, Church, Jacobs, Martinez & Knuth, 2013; Singer & Goldin-Meadow, 2005). Alibali, Nathan, Wolfgram, Church, Jacobs, Martinez and Knuth (2013), studied the use of spontaneous gesture produced by instructors in mathematical lessons on slope and intercept in a classroom setting. They found that teachers produce gestures with their accompanying speech when reviewing previously taught concepts and when introducing new concepts. However, they relied more heavily on gesture when introducing newer concepts. In addition, students gained more knowledge from more frequently produced gesture in the lessons with new concepts, although gesture produced with concept review was also beneficial for learning. In a study examining rehearsed gesture, Ruekert, Church, Avila and Trejo (2017) used video instruction to teach undergraduates a statistical concept (analysis of variance; ANOVA). Results showed that video instruction that included gesture showed significantly greater learning than instruction without gesture for undergraduate students.

Other research has found that when learners produce gestures in one-on-one math tutorial sessions with teachers, their gestures are often picked up by their teachers and used in the next instructional move. Learner who produce gestures also leads to more correct problem-solving after training compared to those learners who do not produce gesture during the instruction session. (Goldin-Meadow & Singer, 2005). In this study gesture functioned to communicate newly developing concepts that were not produced in the learner’s speech to further the learning discourse.

How Does Gesture Facilitate Learning?

As previously mentioned, gesture allows abstract concepts to become more concrete. Where visual perception is lacking, gesture fills in the gaps by imitating moving objects on a perceivable scale. Transforming abstract concepts to concrete ones allows the learner to grasp the concept to further develop their learning (Vallotton, Fusaro, Hayden, Decker, & Gutowski, 2015; Goldin-Meadow, Levine, Zinchenko, Yip, Hemani, & Factor, 2012). Furthermore, gestures that are produced with speech allow learners to build a foundation for understanding abstract concepts without having the domain specific language (Roth, 2003).

Other studies have shown that novice learners will often produce the correct scientific model or mathematical problem-solving strategy in gesture before expressing the concept in speech (Goldin-Meadow & Singer, 2005; Singer, Radinsky & Goldman, 2008; Roth, 2003; Singer, 2017). This often leads to more learning compared to those who did not produce gestures on particular concepts (Singer, 2017). For instance, Singer, Radinsky, and Goldman (2008) video-taped children in a science classroom while working in small groups to track their learning of plate tectonics over 11 weeks. They found that children spontaneously produced gestures while constructing an understanding of volcanoes and earthquakes using a data visualization tool (Geographic Information System) in small groups. Specifically, they found that correct models of plate movements and concepts appeared in gesture before they were conveyed in speech. Additionally, children also used each other’s gestures while co-constructing these plate movement concepts and often added or changed each other’s plate models in gesture. Overall, children who produced the correct models in gesture during their small group work were more likely to correctly construct and apply meaning of the science concepts in speech on a posttest at the end of the study. What is not clear from this study is whether children’s correct models of plate tectonics appeared in gesture and speech due to observing their peer’s gestures and/or producing their own gestures while constructing their own models of plate tectonics. In the current study, the goal is to examine the effect of gestural input on the learner’s understanding of plate tectonics.

Across development, gestures accompanying speech also helps the listener’s comprehension and memory of the message being conveyed (Carlson, Jacobs, Perry, & Church, 2014; Crowder, 1996). The duel coding theory explains the benefits of using both verbal and nonverbal modalities or systems for the processing of imagery and linguistic information (Paivio,1986; Clark & Paivio, 1991). Essentially, gesture in conjunction with speech can improve learning by allowing the concept to be processed and encoded into memory in two modalities, audio and visual. If one memory trace fails, like audio, the other, visual, can help with the retrieval of the message. In a study examining spatial-contiguity and modality in multimedia learning, Moreno and Mayer (1999) found that students who received a lesson on lightening through computer narration paired with visuals had increased learning measured by retention, transfer, and matching, in comparison to students who received only narration or only visuals. Overall, they found that students learned better when visual images and narration were physically and temporally close. Processing new information with two modalities is beneficial for storing that information into memory, which is why gesture may be beneficial when paired with speech. Specific types of gestures, such as representational gesture, may help learning through the contiguity of visual information and the instructional speech.

While most research has focused on the role of gesture in learning mathematical concepts, less research has focused on the area of scientific reasoning, particularly in undergraduate learners. Gestures may be well suited as an expressive modality in science because learners are often asked to produce, describe, or explain natural phenomena (Roth, 2003). Hemmerich and Wiley (2002) found that undergraduates struggled with explaining earth science phenomena (specifically earthquake and plate tectonics) after reading materials on the topic. They suggested that students find it difficult to integrate and visualize earth science concepts in order to understand the structure and behavior of the planet. Gesture allows for mental visualization and explanations of movement that cannot be seen in nature, both assisting in construction and communication of the mechanisms (Crowder, 1996). Perhaps one of the best examples of the potential benefits of gesture in science is the previously mentioned Singer, Radinsky, and Goldman (2008) study. Their work with children is the basis of the current study with undergraduate students.

Current Study

Research examining the topic of plate tectonics is limited even though it is a topic taught at both primary and secondary school as well as college and is less understood even by adults (Hemmerich & Wiley, 2002). Fewer studies have examined the role of gesture in the learning of plate tectonics (Singer, Radinsky, & Goldman, 2008). The concept of plate tectonics is a useful topic when studying gesture because it occurs on a large time scale, and the mechanisms of earthquakes and volcanoes are not visually perceptible. The concept of plate tectonics is a relevant example of the potential for gesture to transform abstract concepts into concrete visuals to help facilitate understanding. The current study examined undergraduate's understanding of the topic using a videotaped lesson on plate tectonics (i.e., the causes of earthquake and volcanic activity). The study also aimed to provide a causal relationship between instructional gesture and learning. Unlike most of the previous research, the current study will look at various types of gesture and their impact on learning.

The current study manipulated gesture in three instructional conditions: *representational gesture*, *beat gesture*, and *no gesture*. The *representational gesture* condition was comprised of both iconic and deictic gestures (i.e. using hand gestures to represent plate tectonic movement and pointing to and tracing maps and diagrams). The *beat gesture* condition was used to assess whether gesture's impact on learning was due to conveying substantive information or due to emphasizing or attention being drawn to particular aspects of the instructor's speech. The *no* *gesture* condition served as a control to assess the effectiveness of any type of gesture. Learning was measured by scoring a five-question open-ended pretest and posttest. We hypothesized that instructional gesture would promote more learning of concepts in plate tectonics compared to no gesture.

Method

Participants

There was a total of 45 Bridgewater State University undergraduate students who participated in the study, 34 females, 10 males, and 1 identified as “other”. The mean age was 20 years (ages ranged from 18-50 years) and the sample consisted mostly of Caucasian individuals (48.89%) along with 22.22% African American, 11.11% Hispanic, 17.78% identified as “other”. Participants were drawn from the Psychology subject pool at Bridgewater State University, Massachusetts. A listing for the study was posted on the Psychology Student Research Participation System (SONA). The study took place at the Psychology laboratory at Bridgewater State University. Participants received incentive in the form of a half-hour of credit towards Introduction to Psychology course requirements. There were 15 participants in the *representational gesture* condition, 15 in the *beat gesture* condition, and 15 in the *no gesture* condition.

Procedure

Participants received a written consent form detailing the purpose of the study and indicating their ability to withdraw from the study at any point. Each participant was randomly assigned to one of three conditions; *representational gesture, beat gesture,* or *no gesture*. All participants were individually administered a pretest, watched a short seven-minute instructional video, and then they were administered a posttest. Each session lasted approximately 30 minutes.

Materials

Participants were asked to complete demographic questions, asking their age, gender, and ethnicity. A five, open-ended question pretest was administered to participants before instruction. (See Appendix A). The questions aimed to assess the participants' previous knowledge on the definition of plate tectonics, the causes of earthquakes and volcanic eruptions, as well as, the locations on plate boundary maps where earthquakes and volcanic eruptions occur. Participants were then instructed to watch a video lesson on the topic of plate tectonics and the formation of volcanoes and earthquakes. Finally, participants were administered a posttest. The posttest was identical to the pretest and was used to measure participants' change in understanding of the topic after the video lesson.

Topic of Instruction

Participants were given an instructional video lesson on the topic of plate tectonics. The instructor remained unchanged in appearance and read the same script for all three videotaped conditions. All instructional videos contained the same maps and diagrams. (See Appendix B). The only difference in the conditions was the type of gesture produced by the instructor, or no gesture at all. In the *no gesture* condition, participants were exposed to an instructional lesson without gestures. This group acted as a control, monitoring the improvement in learning from the instructional lesson alone. The instructor in the video clasped her hands the entire video. (See Appendix C). In the *beat gesture* condition, participants received the instructional lesson with the addition of beat gesture. The instructor moved her hands how she felt naturally, beating them rhythmically with her speech, therefore conveying no substantive information on plate tectonics. (See Appendix C). In the *representational gesture* condition, participants received the instructional lesson with the addition of iconic and deictic gestures. Through iconic gesture, the instructor conveyed the movement of plate tectonics, using two flat palms representing plates and moving her hands in space to represent the movement of the plates (e.g., subduction, rift, buckling, etc.). (See Appendix C). Through deictic gesture, the instructor pointed to the images and traced fault lines on the maps with her index finger. The *beat gesture* condition was included in the study in order to assess whether gestures impact learning simply by drawing the attention of the participant to the lesson or whether gestures impact learning by conveying substantive information on plate tectonics, as in the *representational gesture* condition. After the participants were exposed to the instructional lesson, they were administered the posttest.

Coding and Analysis

All five responses from both the pretest and posttest were coded using a 5-point system for each individual question. A point scale was created for the written responses of the questions, ranging from 0-4 points. A participant could score a total of 20 points for their test, but each question was scored individually. The coding of concepts in open-ended responses was based on a previously developed system for coding concepts in speech in oral explanations of plate tectonics (Singer, Radinsky, & Goldman, 2007). A written response was assigned a score of 0 points if the answer contained inaccurate/unrelated content or if the participant indicated that they did not know the answer. Responses scored 1 point were related to the topic but too vague to convey understanding. Responses scored 2 points showed more in depth understanding but lack the relevant concepts and terms. Responses scored 3 points showed understanding but lacked terminology. Finally, responses scored 4 points showed in depth understanding using the relevant concepts and terminology. For example, for question one, “Have you heard the word plate tectonics? What does it mean?” a response scoring 0-points would be “unsure.” A response scoring 1-point would be “earth’s plates,” 2-points would be “plates under the earth,” 3-points would be “plates that move/shift” and finally a response scoring 4-points would be “plates under the earth’s crust that move/shift.”

Reliability was established on the scoring system by having two coders compare their assignment of points to individual responses on a subset of the pretest and posttest data. Specifically, once all of the responses were assigned points on both the pretest and posttest for each participant, a second coder assigned points on a subset (one third of all data) of the pretest and posttest data. A total percentage of agreement among coders was 88% on the written responses. Any disagreements were resolved through discussion.

Results

The current study analyzed changes in learning from pretest to posttest using a two-way, mixed factorial design, where the within-subjects factor was time (pretest/posttest), and the between-subjects factor was condition. There were 15 participants in each of the three conditions (45 total) that were scored and analyzed. Analyses aimed to explore the effect of instruction and prior knowledge effects on learning. It was hypothesized that instructional gesture would promote more learning of concepts in plate tectonics compared to no gesture.

Was the instruction effective, independent of condition?

Before examining the effects of instruction on performance, participants in the *representational gesture* condition produced an average of 5.60 correct solutions on the pretest (*SD*= 4.56). Participants in the *beat gesture* condition produced an average of 6.13 correct solutions (*SD*= 4.12) and those in the *no gesture* condition produced an average of 6.93 correct solutions (*SD*= 4.57).

Overall, the video instruction (both when instruction was accompanied by representational and beat gestures and when it was not accompanied by gesture) produced learning. Participants in the *representational gesture* condition produced an average of 8.47 (*SD*= 4.03) correct solutions on the posttest. At posttest, the average number of correct solutions produced in the *beat gesture* condition was 9 (*SD*= 4.34) and 9.07 in the *no gesture* condition (*SD*= 3.65). Overall, there was a statistically significant difference between the average number of pretest (M= 6.2) and posttest (M= 8.84) correct solutions, paired $t(44)=-4.928$, $p < .05$. Thus, the instruction was effective independent of condition.

Did instruction with gesture result in more learning than instruction with no gesture?

We conducted a repeated measures ANOVA, with time (pretest and posttest) as the within-subjects factor and instructional condition as the between-subjects factor. The *representational gesture* condition showed a larger increase in learning compared to the *beat gesture* and *no gesture* conditions (average increase of 2.6). The *beat gesture* condition (average increase of 2.34) also improved more than the *no gesture* condition (average increase of 2.07). (See Figure 1). There was main effect of time on learning, $F(1)=23.407$, $p > .05$, however, there was no statistically significant interaction of time by condition on learning from pretest to posttest, $F(2,42)=.203$, $p > .05$.

Was there an effect of prior knowledge on learning?

Participants' ability to learn could have been affected by their prior knowledge or how much they knew on plate tectonics prior to instruction. This in turn, could have interacted with instruction. In order to examine the possibility of an effect due to prior knowledge, we conducted a between-subjects, two-way ANOVA and included prior knowledge status (low and high prior knowledge) and instructional condition. Gain scores were included and calculated for each participant by calculating the difference in pretest and posttest scores. Each participant was categorized as a low or high prior knowledge based on their pretest scores. Participants could score a possible 20-points on the pretest (scores ranged from 0-18). Based on the median split, pretest scores between 0-5 points were categorized as low, and scores between 6-20 points were categorized as high. Twenty-three participants were categorized as low prior knowledge, and twenty-two participants were categorized as high prior knowledge. Overall, participants who were categorized as low prior knowledge had significantly higher average change scores (*M*= 4.30, *SD*=3.52) than those who were categorized as high prior knowledge (*M*=0.86, *SD*=2.71), *F(1)*=13.051, $p < .05$. However, there was no statistically significant interaction between prior knowledge and instructional condition. On average, low prior knowledge learners had higher gain scores compared to the high knowledge learners when instructed with both *representational gesture* and *no gesture*. However, there was little difference between low and high prior knowledge on average gain scores when instructed with *beat gesture.* (See Figure 2).

Discussion

In the current study, we attempted to show a relationship between representational and beat gesture and learning of plate tectonics through the use of video instruction. Participants received video instruction with the inclusion of either representational gestures, beat gestures, or without gesture. We found that, overall, learning increased across all conditions. Although it was not statistically significant, the *representational gesture* condition increased learning more from pretest to posttest than *beat gesture* or *no gesture* conditions.

Similar studies examining gesture and instruction found significant learning benefits when instructed with meaningful gesture. Using a similar methodology, Rueckert, Church, Avila and Trejo (2017) also studied representational gesture with an undergraduate population. Their study used video instruction to teach a statistical concept (ANOVA). They found that there was a greater increase in learning from pretest to posttest in the speech plus gesture condition than the speech alone condition. The results from the Rueckert, Church, Avila and Trejo (2017) study coincide with the pattern of results in the current study, although our results were not statistically significant. This difference could have been due to our stimulus videos, in that the *representational gesture* condition includes both iconic and deictic gestures, whereas the other study may have only used one type of representational gesture in their instruction.

Furthermore, less research has focused on the role of beat gesture in mathematical and scientific instruction. In the current study, we included beat gesture to help elucidate the role of gesture in learning. Beat gesture acted as a control to test if gesture increased learning through conveying information or by drawing attention. Learning did increase in the *beat gesture* condition, meaning that it could have improved learning by drawing attention to the speaker, or emphasizing particular places in the speech instruction. In a study assessing the same three conditions as the current study, using video instruction on the topic of cell mitosis, Kang, Hallman, Son and Black (2012) found that the representational gesture condition numerically scored the most points, and the *beat gesture* condition numerically scored the least. Participants were scored on a posttest measuring retention, immediate transfer, what-if, and drawing. Although participants in the *beat* gesture conditions did perform better than the *no gesture* condition in some aspects, they lacked in retention and drawing. Only 1/18 of participants expressed movement through arrows or action words in their drawings of mitosis processes, although there was no significant difference in action information between the three groups. The difference in results from the current study and other research could be due to a limitation in our *beat gesture* condition instruction. Beat gesture can be difficult to script because they are more natural, and our instructor could have unknowingly emphasized important points with larger beat gestures, which could have impacted learning as if it was a representational gesture.

We acknowledge that there were other limitations that could have affected the statistical significance of the results. One limitation was the sample size. A larger sample size would allow for more power and perhaps reach statistical significance, and extreme scores would not have as much of an impact on the overall means. Further research could address this limitation by collecting more data.

The measure of learning that was used in the current study could also be improved upon in the future. The phrasing of questions on the pretest/posttest could have led to confusion and resulted in lower scores. The questions stated, “Where do you think volcanoes/earthquake occur? Why?” The question was meant to assess why the phenomenon occurred at those areas, not why do they occur overall, which is asked before as well. Those who interpreted the “Why?” as “Why do they occur?” instead of “Why do they occur there?” may have received a lower point score due to incompletely answering the question. Pretests/posttest questions should be elaborated to avoid confusion, and ensure the questions are asking what they intended to ask. Further research can assess the validity of the learning measures.

Beyond addressing limitations, the current study can be modified in various ways to expand upon current research. Studies have shown that producing gesture may be beneficial for learning if the gesture conveys substantial information (Goldin-Meadow, Levine, Zinchenko, Yip, Hemani & Factor, 2012). The current study focused on observing gesture in undergraduate students and data suggests that there could be a relationship between observing gesture and increased learning. We did not explore aspects of producing gesture, but further research could explore the potential outcomes of undergraduate students producing gesture during instruction and the subsequent learning.

Further research could also expand upon the role of prior knowledge on learning. The results stated that participants who were categorized as having low prior knowledge had significantly higher average change scores than those categorized as having high prior knowledge. This could have been due to the fact that those with low prior knowledge paid more attention to the lesson in order to gain understanding, whereas those who felt they had a good understanding did not pay as much attention to gain more knowledge. High prior knowledge could affect effort and attention in participants, leading to lower change scores. More data collection could help to elucidate the role of prior knowledge on learning and the interaction of prior knowledge and gestural instruction.

The findings of the research have many implications in educational contexts and in learning contexts with technology. Through the current study, video instruction significantly increased learning, which is helpful when discussing online learning. Having an instructor who is visible in the video and able to point to specific objects or convey mechanisms through gesture, can be more helpful than an audio recording with coinciding slides. Although it was not statistically significant, the data suggest that representational gestures, which are more specific and concrete, are the most helpful for learning, specifically in individuals with low prior knowledge. This is helpful for both online and in class learning, encouraging teachers to produce representational gestures to coincide with speech in order to improve learning, especially in abstract topics with novice learners. In summary, both the learners and the instructor play a role in learning, and gesture is a useful tool in the learning process.

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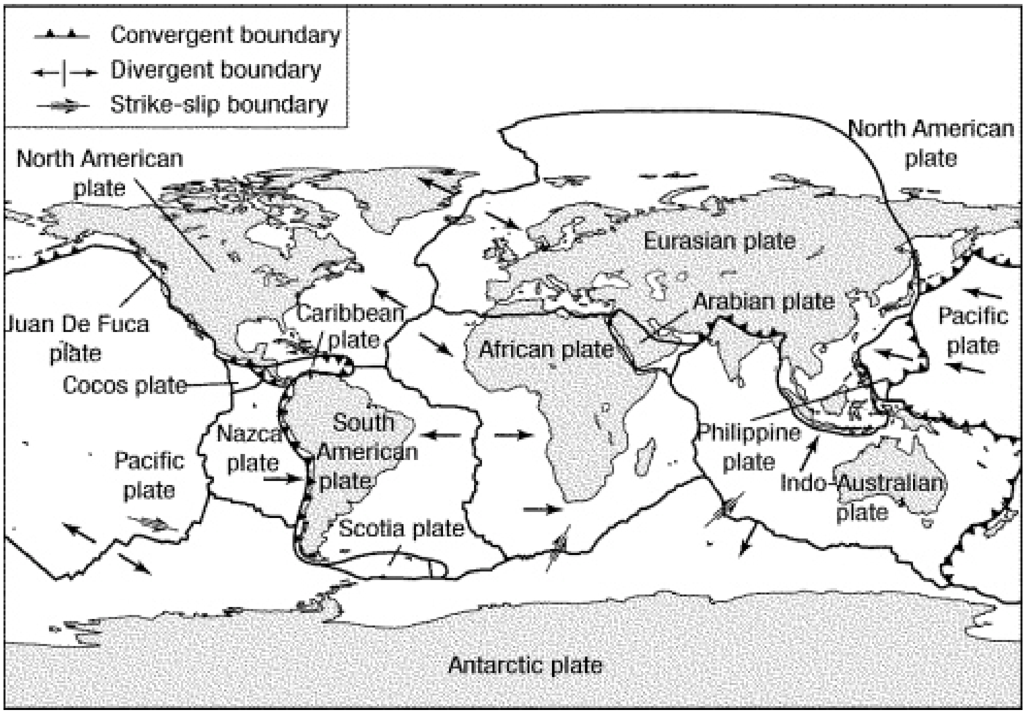
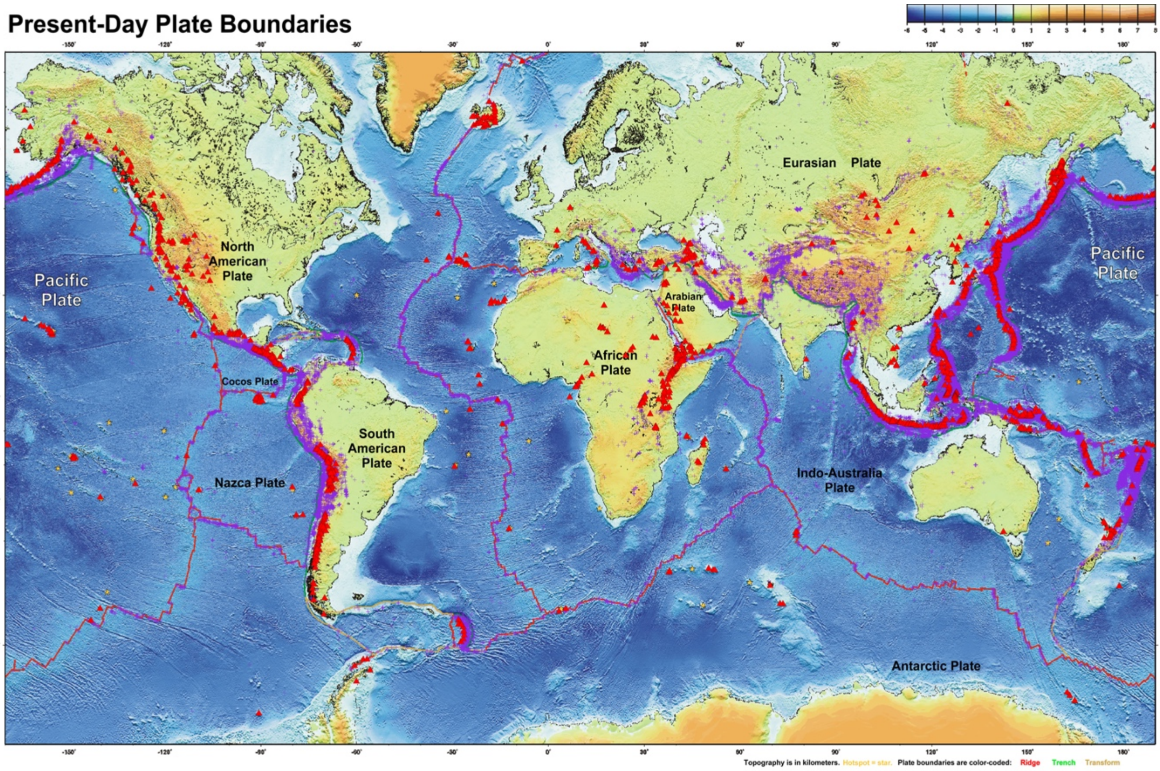
Appendix A

Please answer these questions as best as you can. It does not matter if you are right or wrong. We are interested in what people know about earthquakes and volcanoes so that we can figure out the best way to teach people about these concepts.

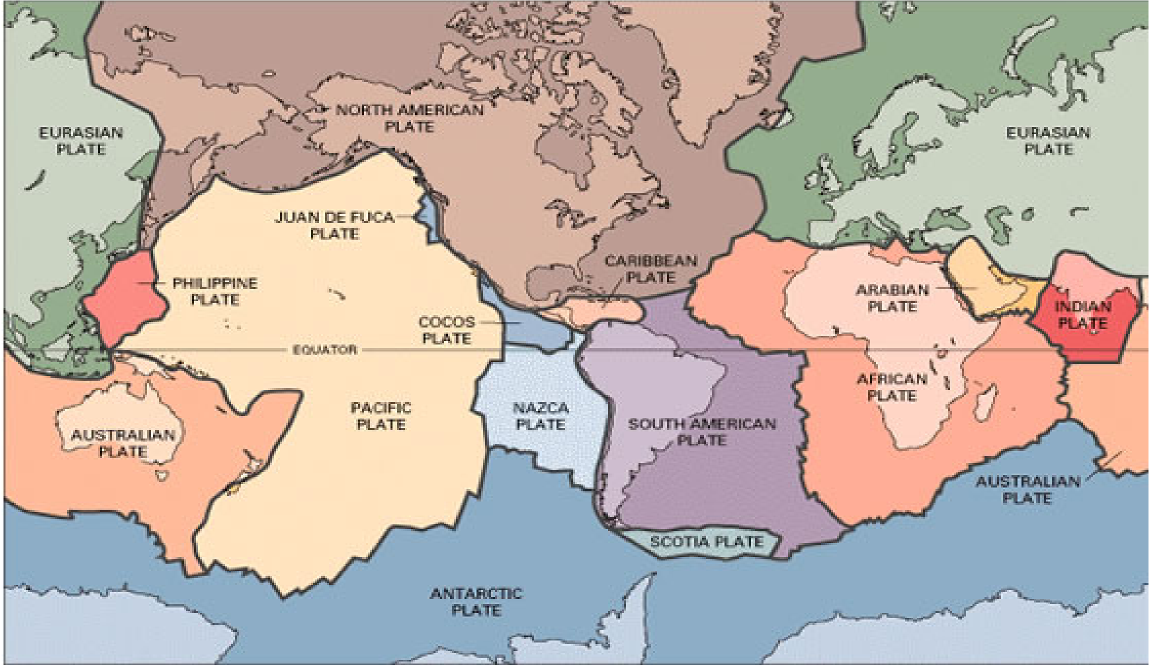
1. Have you heard the word plate tectonics? What does it mean?
2. Do you know what causes an earthquake?
3. Where do you think earthquakes occur on the map (refer to map and circle areas that apply)? Why?
4. Do you know what causes volcanic eruptions?
5. Where do you think volcanic eruptions occur on the map (refer to map and circle areas that apply)? Why?



Appendix B



Map 1.



Map 2.

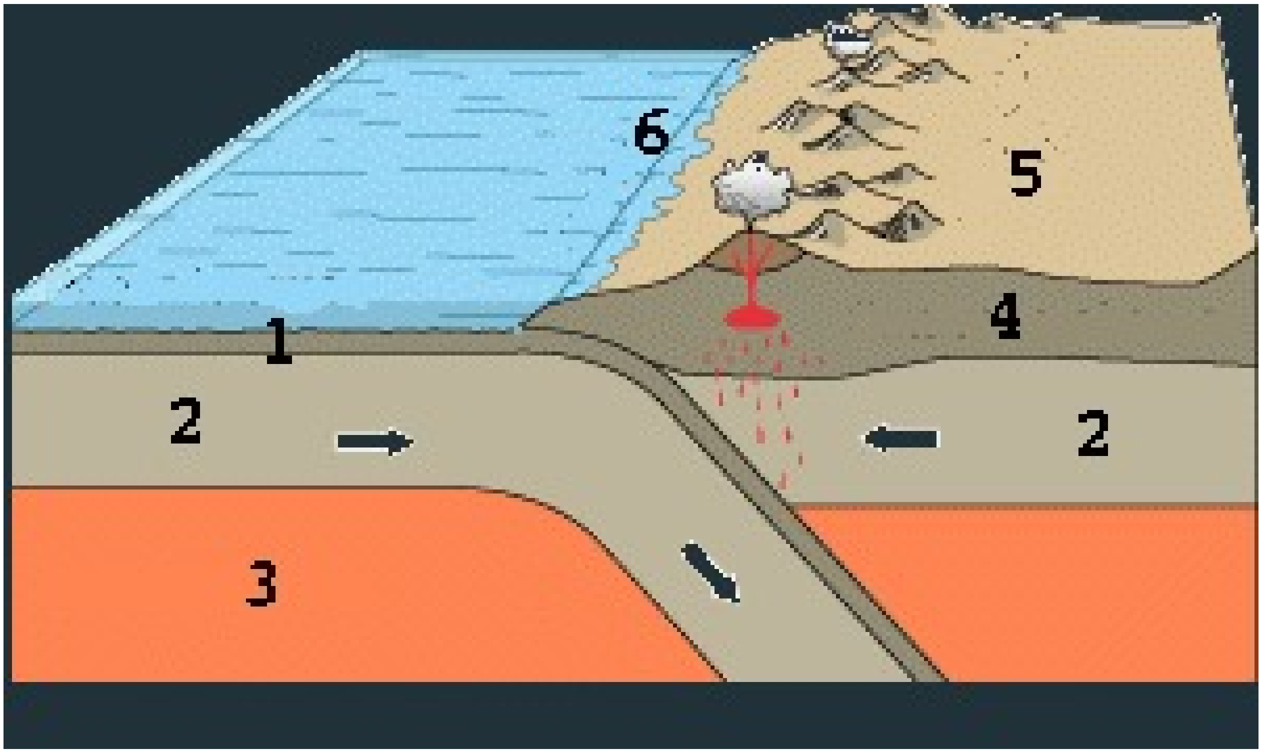


Image 1.

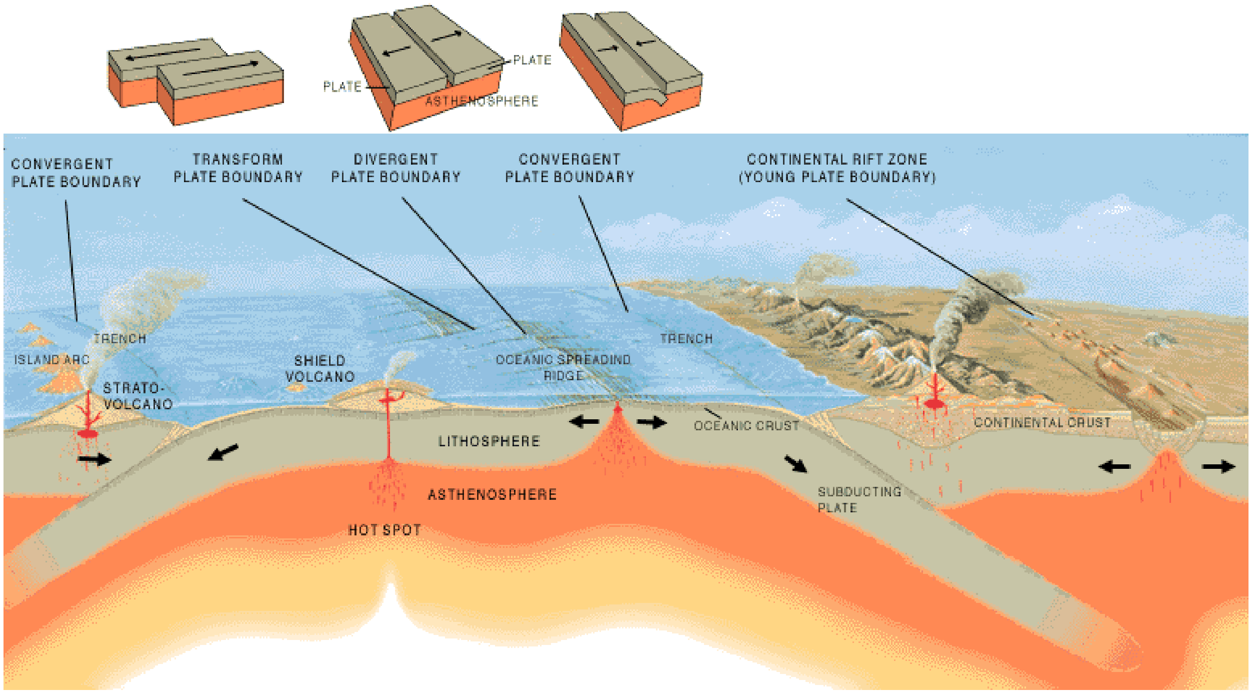
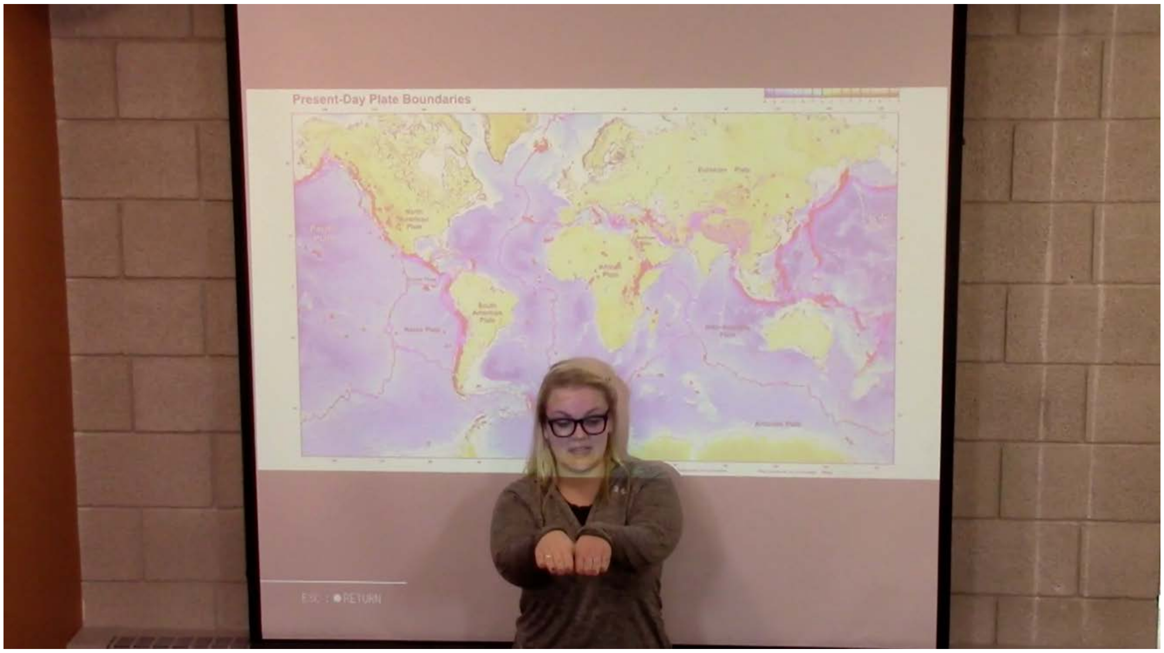
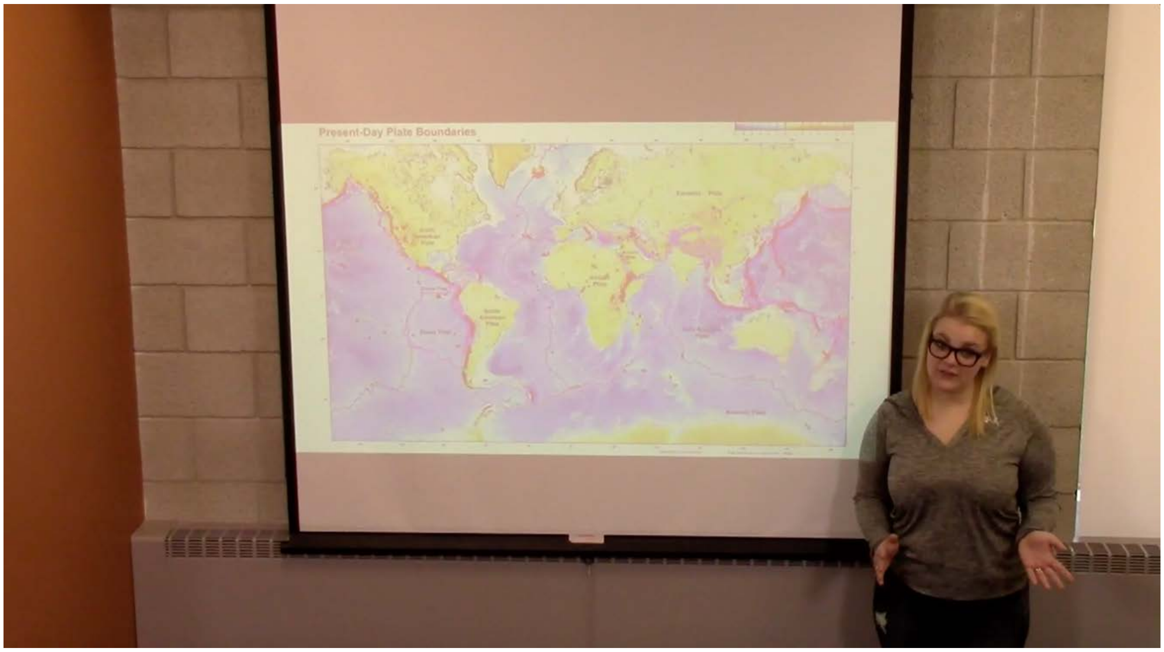


Image 2.

Appendix C



Representational Gesture.



Beat Gesture.

No Gesture.

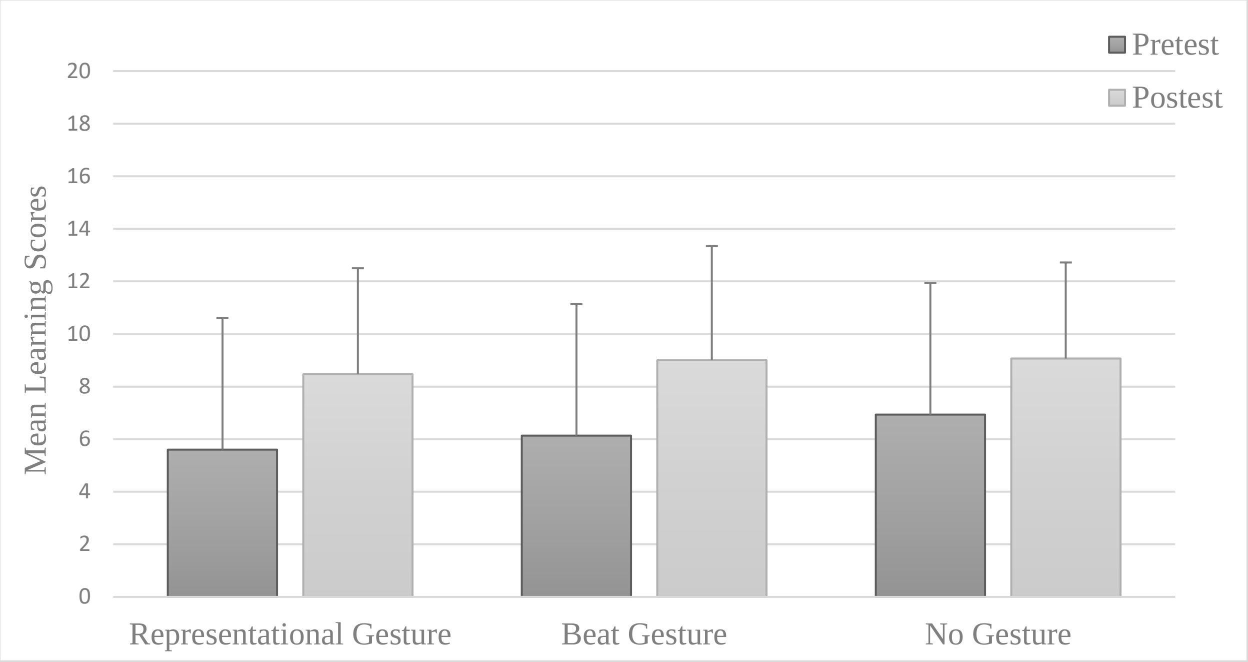


Figure 1. Mean learning scores on pretest/posttest for each instructional condition.

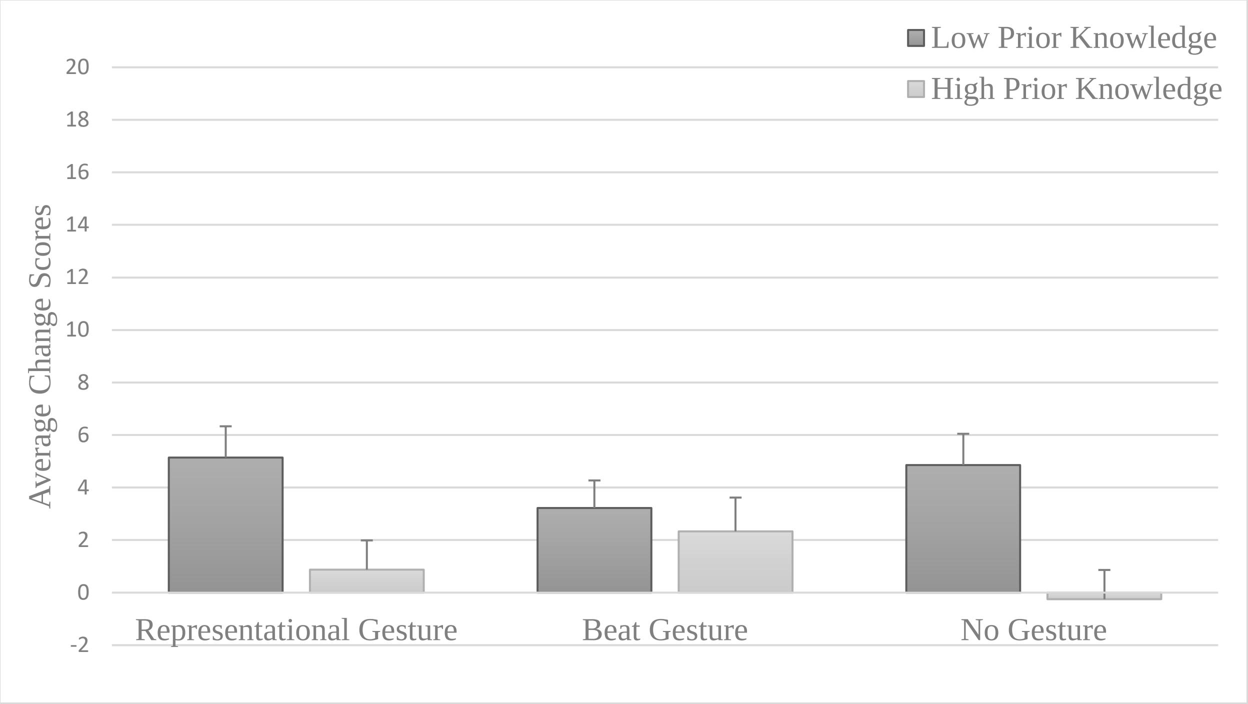


Figure 2. Average change scores for low and high prior knowledge classifications for each instructional condition.