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Gesture in Synthesizing Student Contributions in Whole-Class Discussion of Graphical Representations of Energy

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Abstract: Gesture's role as a powerful and versatile tool for instruction, especially in STEM domains, is well-established. However, many specific teaching moves accomplished through gesture remain understudied. Using interaction analysis, we examine how an introductory university physics instructor uses gesture during whole-class discussion of graphical representations of energy conservation to *synthesize* multiple student groups' solutions. This embodied, whole-class discussion orchestration move distills and summarizes the key points of the lesson while highlighting student contributions and addressing misunderstandings.

Introduction

A wide range of research shows how students and teachers use representational gesture – visible arm and hand motions that resemble objects, actions, and events in STEM education (for a review, see Singer, 2017). Students use gesture as part of sense-making and knowledge construction and teachers employ gesture as part of sharing information and linking ideas together (Alibali et al., 2014). In this study, we use a detailed microanalysis of interactions in an undergraduate physics classroom to illustrate how instructors draw on gesture to *encapsulate the collective contributions of the entire class* as part of the co-construction of knowledge. This study offers valuable insights into how teachers' gesture can *synthesize* students' contributions as part of culminating whole-class discussions, offering valuable insight into an overlooked practice for lesson closure.

Theoretical framework

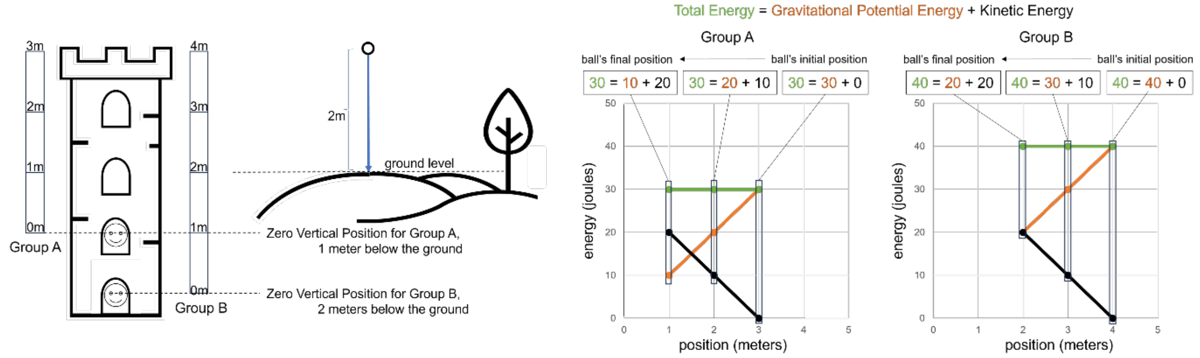
Dialogue with peers and instructors provides critical opportunities for learning science and mathematics (Hammer et al., 2012; Mortimer & Scott, 2003; O'Connor & Michaels, 1993). In dialogic class discussions, teachers elicit students' ideas and invite students to participate in the co-construction of knowledge together (Robertson et al., 2015). As part of this process, teachers use *revoicing*, where they repeat students' ideas and broadcast these ideas to the class (O'Connor & Michaels, 1993). Eliciting and revoicing student ideas provides important possibilities to provide feedback on students' ideas, and to address misunderstandings. Teachers also summarize and synthesize ideas to establish the take-aways of a lesson in whole-class discussions (Michaels et al., 2016). Current research mainly examines how these practices are conducted through speech, with less emphasis on the role of gesture. We see students' and teachers' embodied, multimodal communication as critical aspect of how knowledge is shared, refined, and summarized. Representational gesture plays an important role in how teachers notice and respond to students' ideas in class (Alibali et al., 2019; Flood, 2021; Flood & Harrer, 2023). In particular, teachers repeat and reformulate students' representational gestures as part of *multimodal revoicing* (Arzarello, 2009; Shein, 2012) in whole-class discussions to refine and broadcast important forms of embodied and visuospatial knowledge with the classroom that students have shared (Flood, 2021). We contribute an in-depth study of a whole-class interaction to better appreciate the role multimodal revoicing can play in classrooms to synthesize students' ideas and lesson take-aways.

Methods

This study emerged from a broader investigation of how undergraduate students solve problems by creating graphical representations to model energy dynamics in *Collaborative Learning through Active Sense-Making in Physics* (CLASP; Potter et al., 2014) *Discussion Laboratory* at a large West Coast University in the United States. We examined video of six groups of 3-4 students working on the "dropped ball problem". We present an in-depth analysis of an extract of whole-class interaction as a revelatory case (Yin, 2009). Our interaction analysis (Jordan & Henderson, 1995) focuses on how meanings are made by participants line by line, using a variety of semiotic resources including talk and gesture. We transcribed speech (black text) and bodily actions (blue text), with a black box outlining those which occur at the same time. Other activities occurring are denoted with italics.

In the problem, a 1-kilogram ball falls from 2 meters above the ground on Earth's surface, where the acceleration due to gravity is approximately 10 meters per second squared. Each group has a different observation point (and consequently, different measurements for initial and final positions relative to their respective observation points), shown for Group A and Group B in Figure 1. Groups were asked to draw three different lines showing the relationship between energy and vertical position of the ball: an orange line for potential energy (PE), a black line for kinetic energy (KE), and a green line for total energy (E_t). The total energy of the ball, which is the sum of the kinetic energy and the gravitational potential energy, is determined by its gravitational potential energy at the position it was dropped from. By comparing different groups' graphs, students can analyze how the observation point impacts potential energy, kinetic energy, and total energy.

Figure 1
The Dropped Ball Problem with Graphical and Algebraic Representation of the Conservation of Energy of the Ball



Findings: Instructor gesture for synthesizing graphical representations

After working in small groups, the instructor asked students to look around at other group's whiteboard responses and identify the similarities and differences in the graphical representations. During the following whole-class discussion, the instructor invites students to share what they observed and records their contributions on a whiteboard at the front of the room. After several students share, Angi (a student) adds that every graph has the same orientation of intersecting potential energy and total energy lines (Figure 2: Line 01), different total energies, and different slopes for each line (F2:11,12). She uses gesture (F2:02) to share her first point.

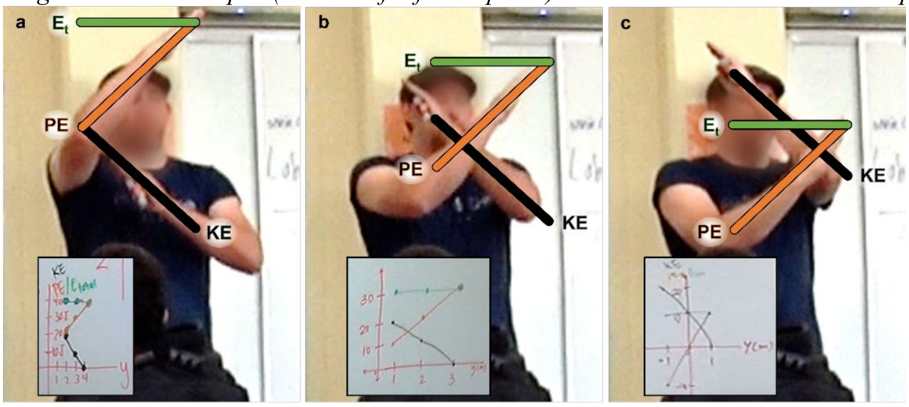
Figure 2
Instructor's Gesture for Synthesizing Students' Contributions Surrounding the Graphical Representation of Energy

Excerpt 1
01 **Angi:** Well we said that like potential energy and E total intersect like in, on all the graphs.
02 PE and E_t Lines Gesture
03 **Inst:** Mmhmm.
04 **Bree:** They're connected at, like, the same position.
05 **Angi:** Mmhmm.
06 **Inst:** Every single board has this 7 on it. Every single board has the number 7 written like this.
07 Writes a 7 on board
08 Check it out.
09 *Students throughout classroom chatter.*
10 **Inst:** Mmkay. What's different?
11 **Angi:** Uhh we said that the E total values are different and that like the slopes of the line are
12 different.
13 **Inst:** Actually the slopes should be all the same.
14 **Angi:** Oh.
15 **Inst:** Mmkay? Cause everyone has that same 7 and everyone has a black kinetic energy
16 like this. Everyone has those two elements. Just they're lined up differently.
17 Combined Graphs Gesture

After Angi shares, the instructor uses a *synthesizing gesture* – the "Combined Graphs Gesture" – to capture and consolidate the core points of the lesson revealed by comparing all the graphs: (1) that the specific values of potential energy and total energy are arbitrary and determined based on the chosen coordinate system, (2) the changes in potential energy and kinetic energy are the same regardless of the coordinate system, and (3) the rates of change in potential energy and kinetic energy (and therefore, the slopes) are also the same. The instructor's Combined Graphs Gesture (F2:17) is an iconic representation that dynamically illustrates the various graphs created by multiple groups emphasizing the important similarities and differences that were unearthed throughout the whole-class discussion: Figure 3 shows how students' graphs on the group whiteboards around the classroom are reflected in the instructor's gesture. The instructor's right arm shows potential energy (orange line), while his left arm shows kinetic energy (black line). The total energy (green line), although not represented in the gesture due to physical constraints, is implied, and can be seen "as if" it is present and has different values (since it would appear at different heights). The position and movement of the instructor's arms show (i) the different relative locations of the energy lines on the graph (the locations of the arms change in space), (ii) the constant total changes in the potential and kinetic energies (the vertical rise of the arms stays the same), and (iii) the unchanging slope of the lines signifying the rate of change of energy (the angles of the arms stay the same).

Presenting each graph variation (Figure 3a, b, and c) in a sequence *links* (Alibali et al., 2014) the different graphical representations together. By doing so, the instructor *synthesizes* students' meaningful contributions during the whole-class discussion, aligning them with the disciplinary objectives surrounding conservation of energy, visibly transforming each group's graph into the others' and allowing students to see what changes (what is different) and what stays the same (what is similar) across variations.

Figure 3
Original Student Graphs (bottom left of each panel) and Instructor's Combined Graphs Gesture



The instructor's Combined Graph Gesture also accomplishes the important function of revoicing student Angi's gestured contribution (F2.01-02) and addressing the misunderstanding conveyed in her contribution that "the slopes of the lines are different" (F2.11-12). While introducing the Combined Graph Gesture, the instructor says "Everyone has that same 7 and everyone has a black kinetic energy line like this. Everyone has those two elements. Just they're lined up differently" (F2.15-17). This statement calls back to earlier in the exchange, when Angi made a gesture while explaining her group's contribution that "potential energy and E total intersect" on all of the groups' graphs (F2.01). She used both hands to depict this, bringing her hands together with palms flat so that the middle fingers from both hands are touching each other, and creating an acute angle (F2.02). The instructor's gesture recognizably draws on many of the same characteristics of Angi's gesture; like Angi, the instructor uses both arms, bent at the elbows with flat hands, to represent the different locations of the lines on each group's graph. Thus, the instructor's *synthesizing gesture* both brings together the class's numerous graphs and multimodally revoices and addresses Angi's conveyed misunderstanding.

Concluding remarks, significance, and implications

Several studies have emphasized the importance of rich whole-class dialogues in math and science classes and how increased levels of dialogic discussion positively impact students' conceptual understanding (e.g., Hammer et al., 2012; Mortimer & Scott, 2003). However, the role gestures play in the process is frequently overlooked and undervalued in significance. Our study contributes to prior literature on whole-class interactions and multimodal revoicing in STEM (Flood, 2021; Shein, 2012) by taking a closer look at how an undergraduate physics instructor uses gesture. We propose a definition for a previously undescribed function of gesture: a *synthesizing gesture* is one which (i) culminates a lesson or whole-class discussion, (ii) aligns with learning objectives, and (iii) integrates multiple representations to make student ideas visible and put them in dialogue. This instructor's synthesizing gesture additionally functions to revoice and address elements of the student's response that convey misunderstanding.

Although we cannot say for sure if Angi or others in the class had new insights about the constant nature of the slopes (the misunderstanding addressed by the instructor) or if the relationships between kinetic energy, potential energy, and total energy were fully appreciated, we do note that in the next related problem, Angi demonstrated a strong understanding of the reciprocal relationship between potential energy and kinetic energy, and how to graphically represent this relationship. In this study, it remains unclear how the instructor's gestures directly affected student understanding or long-term learning outcomes. Further research could explore students' perceptions of teacher gestures in STEM classes, their impact on student comprehension, and their role in long-term information retention. We suggest that a teacher's use of gesture – particularly when timed appropriately, such as after a student publicly conveys a misunderstanding – can help to accomplish a myriad of instructional goals. In this interaction, we see its potential to serve as a useful tool for redirecting attention and removing pressure from the student; to position the misunderstanding as useful for learning; and to utilize visuospatial information to address the reasoning underlying the misunderstanding. Further studies could also look at how the explicit use of gesture by teachers and students can shape the error climate (Steuer et al., 2013) in classrooms in productive ways, and impact student engagement over time. Overall, we argue that teachers' multifaceted use of gesture in the classroom has the potential to enhance students' understanding, particularly in dialogic, discussion-based math and science classes.

This study generates a number of implications for STEM instruction. Training instructors about different ways they might attend to and draw on students' gestures, as well as use their *own* gestures may enhance instructors' confidence and skills in orchestrating whole-class discussion to support STEM knowledge co-construction. It may also help support instructors in adopting a dialogic stance in whole-class discussions and responding to and drawing on student ideas (even when these ideas are nonverbal, unfinished, or not quite right) in the moment. The thoughtful use of gesture to revoice student contributions, address misunderstandings, and synthesize lessons in whole-class discussion could be further explored as explicit teaching strategies.

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Acknowledgments

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