How Kinetically-Held Gestures Support Collaborative Problem Solving in Physics

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Abstract: Embodied forms of communication like gesture are essential for problem solving, but we know little about how they are used in group interactions. Drawing on ethnomethodology and conversation analysis (EMCA), we examine how undergraduate physics students use the *temporality* of gesture to orchestrate productive interactions: Using *kinetically-held* (frozen in place) *gestures*, students (1) recruit attention, (2) mobilize responses, (3) weather interruptions, and (4) facilitate extended consideration of elaborated and clarified ideas.

Introduction & theoretical approach

Collaborative problem solving in STEM engages students in productive disciplinary practices and knowledge building (e.g., Engle & Conant, 2002; Roschelle, 1992), but learning outcomes of groups are contingent on the quality of their interactional processes (Barron, 2003; Roschelle, 1992). The learning sciences have documented many interactional resources students use to coordinate interactions during collaborative STEM problem solving, including strategies for releasing tension (Sohr et al., 2018), managing uncertainty (Conlin & Scherr, 2018), and navigating off-task behavior (Langer-Osuna et al., 2020). While we know much about productive forms of *talk* that are conducive to generative collaboration, less is known about how gesture helps orchestrate productive group interactions. In this study, we examine how undergraduate students use the *temporality* of gesture to coordinate collaborative physics problem solving. In particular, we show how students use *kinetically-held gestures* (Kendon, 2004) – suspended representational gestures – to support productive group interactions.

Detailed, mechanistic examinations of interaction are crucial to understand sources of variability in collaboration and how outcomes emerge (Barron, 2003; Koschmann & Zemel, 2009; Roschelle, 1992). Roschelle (1992) illustrated how students must carefully monitor and repair shared understandings in group work: collaborators must not move on from proposals until they have sufficient evidence of shared understanding. Barron (2003) discovered another key interactional characteristic: based on how *responsive* students were to each other's verbally shared proposals, equally competent groups performed dramatically differently on problem solving tasks. Unsuccessful groups ignored, interrupted, and rejected (correct and incorrect) proposals before they were elaborated or clarified. We ask, how might representational gestures shape these interactional processes?

Representational gestures, which illustrate objects and processes (Kendon, 2004), are especially useful for collaborative STEM work because students use their hands and bodies to work out, model, and make sense of scientific and mathematical phenomena together (e.g., Alibali & Nathan, 2012; Roth & Lawless, 2002; Scherr, 2008; Singer et al., 2008; Walkington et al., 2019). An understudied affordance of representational gestures is their temporality. Participants can control how a gesture evolves *over time*. Representational gestures have distinct phases: (a) a *preparation* where the hands leave a resting position, (b) one or more *strokes* that carry semantic information, and (c) a *retraction* where the hands resume rest. A *gesture hold* occurs when, after a stroke is completed, the hands *do not* return to a rest position but remain frozen for a period of time (Kendon, 2004). Holds both illustrate content and project information about participation or turn-taking. They are used to mark turns-in-progress that speakers intend to resume after speech disfluency (e.g., a pause to find the right words), interruptions, or because a speaker struggles to gain attention (Park-Doob, 2010; Sikveland & Ogden, 2012). Holds can also be used to mobilize responses from participants, e.g., by demonstrating the speaker's expectation that a listener should supply an answer to a pending question (Kendon, 2004).

Study context, methods, and findings

We examined 11 groups of 3-4 students completing 4 problems from the Collaborative Learning through Active Sense-Making in Physics curriculum (Potter et al., 2014) in an undergraduate physics class (25 hours of video). We identified 100 instances of group members' use of representational gestures where representational gestures were held for more that 1.0 second. All groups used holds. We selected a single interactional sequence to present representative examples of *each* of the different interactional functions of kinetically-held gestures in group work we observed in our collection. Our EMCA-inspired microanalysis traces the temporality of representational gestures, including their preparations, strokes, holds, and retractions to reveal how holds are coordinated with other semiotic resources to organize interaction. Our transcripts adapt (1) Jefferson's conventions for talk*;* (2) Mondada's conventions for gaze, facial expression, and body movement: -- *extended duration,* --> *action continues;* and (3) Kendon's conventions to annotate gesture preparation, strokes, holds, and retractions:

preparation phases ~~~, *strokes* ^^^, *held gestures* ***, and *retractions* -.-.; *beginning and end of phases* are denoted with |. Symbol sequences illustrate the timing of gesture phases, aligned with co-occurring speech syllables and other semiotic activity. Each gray box shows a set of vertically aligned co-occurring semiotic resources, and speech tracks are aligned horizontally to show sequential turns. Gesture is marked in blue, speech in black, and other activity in gray.

Kit, Leo, Ian, and Jen are working on a problem that requires them to model a toy car launcher with a spring inside that gets compressed by the same distance each time a car is loaded. This distance indicates the amount of energy stored in the spring. When the car is launched, the spring decompresses. The energy in the spring is converted to kinetic energy of the car, which is released with a certain initial velocity. Students are asked if *all* cars will have the same launch speed. Kit turns to the group with a proposal: The initial distance should be *greater* than zero, and the *final* distance should be zero because the spring is initially compressed and must return to its relaxed state as the car is being accelerated. Kit's proposal is consistent with the convention that the energy in a spring is zero when it is not compressed or stretched.

Figure 1

Using a representational gesture hold to recruit attention

```
01  kgestrh: ~~~~~~~~~~~~~~~~~~~~~~~|^^^^^^^^^^^^^^|********
                     rPrep               rStroke     rHold 1
02  gaze:    Ian, Jen, & Leo looking at their notebooks-->
03  KIT:     SO::-
04                 (0.2)
05  IAN:                  °What's ou┌r thing for a ┌spring?°
06  KIT:                            └ACTually      └no:-
07  kgestrh: ***********************************
                           rHold 1
08  igaze:   @Ian's notebook------------------>
09  KIT:     (..0.4..) With the spring the fir-
10  kgestrh: ********************************************
                               rHold 1
11  kgestlh: |~~~~~~~~~~~~~~~~~|*************************
                   lPrep                   lHold 1
12  igaze:   @Ian's notebook------------------->looks up
13  KIT:     the initial should be greater than zero.
14  kgestrh: *************************************
                             rHold 1
15  kgestlh: *************************************
                             lHold 1
16  igaze:   @Kit-------------------------------->
17  KIT:     It's not at equilibrium. (....0.6....)
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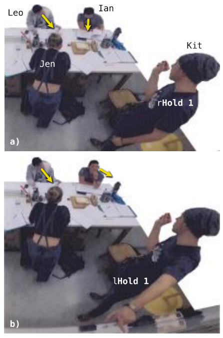


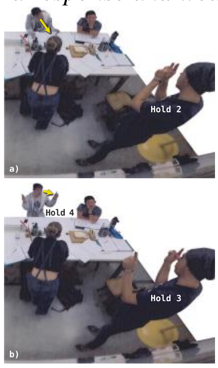
Barron (2003) observed that unsuccessful groups often have issues with *recruiting* each other's *attention* to joint problem spaces (Roschelle, 1992). Making sure a proposal will be adequately considered and understood means ensuring that it is not ignored. Kit turns from the board to his group, making a bid to share a proposal. He begins with "So-" (E1.03) and pauses (E1.04) while moving his right arm out toward the group (r**Prep**, E1.01). Leo, Ian, and Jen are all gazing at their notebooks (E1.02). Without looking up, Ian asks a question about the spring (E1.05). Kit restarts his turn (E1.06) and makes a shrinking pinch shape with his right thumb and index finger (r**Stroke**, E1.01), evoking the image of a spring contracting. He then starts to hold this pinch shape (r**Hold 1**, E1.01; **E1.a**). As the group maintains gaze on their notebooks, Kit starts a third attempted turn in E1.09 and also cuts it off but continues holding his pinch gesture (E1.07). He points to the board with his left hand (l**Hold 1**, E1.11; **E1.b**). With both arms outstretched (r**Hold 1**, E1.10; l**Hold 1**, E1.11), he starts a fourth time, now making a complete proposal: "The initial should be greater than zero" (E1.13). Ian raises his head to look up at Kit (E1.12). With Ian's attention secured and still holding his gesture (E1.14-16), Kit elaborates his proposal, providing additional evidence: "It's not at equilibrium" (E1.17). By deploying several cut-off phrases and false starts, accompanied by a visible gesture held out towards the group, Kit succeeds in not having his proposal be ignored. Speech restarts are an effective tactic for recruiting visual attention as a speaker when trying to take a turn (Goodwin, 2018). However, Kit also deploys a *gesture hold* to *recruit attention:* Continuing to hold his hand outstretched (E1.01-14), he displays he has something to share that requires their attention.

Even when shared attention has been achieved, groups may not acknowledge a proposal (Barron, 2003). An important interactional strategy is to *mobilize a response* (Stivers & Rossano, 2010) when proposals have been shared. After successfully gaining Ian's attention (E1.16 in Figure 1), Kit releases his first gesture hold in Figure 2 and produces a new representational gesture that he holds (**Hold 2**, E2.18; **E2.a**) as he provides additional support for his assertion that the spring is not at equilibrium (E1.17): He says, "you see it's bent right here" (E2.20), bringing both index fingers together vertically and evoking an image of a compressed spring (**Hold 2**, E2.18; **E2.a**). He holds this gesture (E2.18,24) as he gazes at Ian. Ian, still looking at Kit, replies, "Yeah" (E2.22). Kit directs attention to the gesture ("you see," E2.20) and, by not immediately releasing the hold, demonstrates he expects a response: Hold and talk solicit an *assessment* of his assertion made in speech and illustrated in gesture. Making sure they agree that the spring is compressed is useful to re-calibrate their shared understanding of the situation. Kit's utterance and hold *mobilize a response* from Ian who accepts the premise (E2.22). This is key for gathering consensus and moving forward, even though they still disagree about the significance of the premise.

Figure 2

Using a representational gesture hold to mobilize a response and weather an interruption

```
18 kgest:   *************|~~~~~~~~~~|********************************
              Hold 1        Prep                  Hold 2
19 lgaze:   @Leo's notebook----------------------------------------->
20 KIT:     You see it's bent right here.
21                                         (...0:5...)
22 IAN:                                                 Yeah.
23                                                          (.0:3.)
24 kgest:   *******************|^^^^^^^^^^^|**********************
                 Hold 2           Stroke           Hold 3
25 lgest:           |~~~~~~~~~~~~~~|^^^^|~~~~~~~~~~~~~~~~~~~~~~~~~~|
                         Prep       Stroke          Prep
26 lgaze:-->looks up@Kit------------------------------------------>
27 KIT:     ┌And then          ┌wh-
28 LEO:     └>>The initial<<'s └zero. (0:1) And then (0:1)    ┌you=
29 IAN:                                                     Ye└ah.
30 kgest:   ***************************************************
                              Hold 3
31 lgest:   |^^^^^^|**********************************|-.-.-.
             Stroke             Hold 4                 Retract
32 lgaze:   @Kit------------------------------------------->
33 LEO:    =let go ┌of it.
34 IAN:            └Initial's zero for sure.
35 LEO:                                      Right.
36                                                  (.0:3.)
```

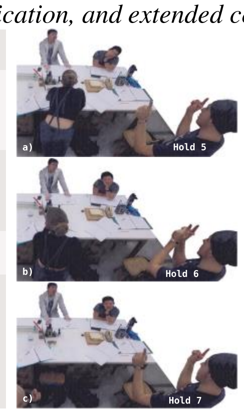


Barron (2003) also observed frequent interruptions in unsuccessful groups, where proposals were cut off and abandoned. Kit uses a third hold to *weather an interruption*: After securing acceptance from Ian, he begins a second part to his proposal in E2.27, saying "and then wh-", as he sweeps his vertical index fingers apart, evoking the image of the spring expanding (**Stroke**, E2.24). Leo, who has been gazing at his notebook, looks up (E2.26) and interrupts with a counterproposal (E2.28,33). Kit *verbally* abandons his turn (E2.27) but keeps his hands suspended in the air (**Hold 3**, E2.24,30; **E2.b**). This displays to the group that he considers his turn incomplete and projects that he will resume it. Notably, Leo also produces representational gestures (E2.25,31) and a gesture hold (**Hold 4**, E2.31; **E2.b**) as he interrupts. He repeats Kit's pinch-shaped "compressed spring" gesture (**Stroke**, E2.25), and he also moves apart his vertical index fingers to repeat Kit's "expanding spring" gesture (**Stroke**, E2.31). Both Leo and Kit hold the same two-handed vertical index finger gesture at the same time (**Hold 3**, E2.30; **Hold 4**, E2.31). Leo holds his gesture past the boundary of his spoken turn, mobilizing an assessment from the group. He successfully solicits a strong agreement from Ian (E2.34). After obtaining acceptance of the counterproposal from Ian, Leo releases his hold (**Retract**, E2.31). All the while, Kit has maintained *his* hold (**Hold 3**, E2.24,30) to *weather the interruption*: Although Leo interrupts with his counterproposal, Kit's maintenance of his turn with the gesture hold in Figure 2 provides a new opportunity for more discussion in Figure 3.

Figure 3

Using gesture holds to allow for elaboration, clarification, and extended consideration

```
37 kgest: ******|^^^^^^^^^^^^^^^^^^^^^^^^^^|**********************
          Hold 3          Stroke                    Hold 5
38 KIT:   and then:: >>when it goes<< back, it goes back to zero
39 kgest: ***********************************
                       Hold 5
40 KIT:   to its equilibrium. (....0:6....)
41 lface:                   ((furrows brow->))
42 lhead:                   ((throws head back->))
43 kgest: **************************************|^^^^|
                       Hold 5                   Stroke
44 KIT:   That's what it's saying.
45                                (...0:5...)
46 LEO:                                         Hmm.
47 kgest: |************************************|
                       Hold 6
48 KIT:   THIS (....0:6....) i::s >>not zero:<<
49 kgest: ^^^^^^^^^^^^^^^|************************|-.-.-.-.-.-.-.-.-.
             Stroke               Hold 7                 Retract
50 KIT:   (.0:2.) this is zero.
51                              (.0:3.)
52 LEO:                                 Huh. (..0:4..) O:kay:?
53 lhead:                            ((nods up))     ((nods down))
54                                                            (0:1)
```



The ultimate consequence of nonengagement with proposals is not having time or space to adequately consider them before prematurely rejecting them and moving on (Barron, 2003). Kit produces another series of holds as he *elaborates* and *clarifies* his proposal, providing new information to the group. The holds both support Kit to make the overall proposal more detailed and explicit, and they make space for the *group's extended consideration* to think about and assess each new piece of information. Kit is still holding his gesture from Figure 2 and has not been able to fully lay out his proposal. He restarts, repeating "and then" (E3.38), and reperforms the "expanding spring" gesture (**Stroke**, E3.37). As he continues talking, he maintains his hands frozen in this position (**Hold 5**, E3.37; **E3.a**) while providing two new important details about the uncompressed state of the spring: When released, the spring "goes back to zero" (E3.38), and *this* is returning "to its equilibrium" (E3.40). Holding the gesture throughout his explanation, Kit *elaborates* his proposal by illustrating the *final position* of the free end of the spring after it is released and has returned to its relaxed state, asserting the *value* of this final position, and establishing that this final, relaxed, position (and *not* the compressed position) should be considered *equilibrium*. In response, Leo leans backwards and furrows his brow (E3.41,42), in a silent but visible display of "doing thinking" (Goodwin, 2018). While still holding the gesture and providing a space for the *extended consideration* of these additional details, Kit elaborates further, claiming he is supported by the lab manual (E3.44). Leo provides a "hmm" (E3.46), displaying his continuing consideration of the proposal. Kit treats Leo's response as an absence of acceptance and understanding, and continues his explanation, using it as an occasion to *clarify*. He speaks with marked emphasis and repeats his gestures, using two holds to illustrate that "This is not zero" (E3.48; **Hold 6**, E3.47; **E3.b**) and "this is zero" (E3.50; **Hold 7**, E3.49; **E3.c**). In these turns, Kit takes the time to make each part of the proposal even more explicit. His holds are now what McNeill (1992) calls *catchments:* repeated images that help bring continuity and coherence through complex explanations. As Kit holds the last gesture (**Hold 7**, E3.49), Leo provides another display of his ongoing consideration ("Huh," E3.52), and then upgrades his acknowledgment of Kit's proposal to an acceptance and claim of understanding ("Okay," E3.52).

Concluding remarks

Our analysis demonstrates how *kinetically-held* gestures can play a role in ensuring proposals are taken up and explored by groups. Holds can provide an interactional antidote against pitfalls that Barron (2003) observed: Kinetically-held gestures can (1) recruit attention to proposals and ideas, (2) mobilize responses to proposals, (3) weather interruptions so proposals can be resumed, and (4) allow for extended consideration of proposals. Our investigation adds to previous studies in STEM education that illustrate how representational gestures are essential tools for learning when students try to make sense of complex phenomena together (e.g., Alibali & Nathan, 2012; Singer et al., 2008; Walkington et al., 2019). We explored the *temporality* of representational gestures and were able to identify and characterize new ways representational gestures contribute to problem solving by organizing and coordinating participation and turn-taking. Our study contributes to broader definitions of competence in collaborative work in STEM: By focusing on uncovering the fine details of the interactional practices students use to build, repair, and maintain a sense of shared meanings in interactions, we were able to recognize more of the assets students bring to STEM work and problem solving.

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