

Laminated Layers of Abstraction in Physics Students' Gesture

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Abstract: Gestures play a key role for physicists and physics students in representing physics entities, processes, and systems. One affordance of gesture is the ability to *lamine* or layer together representations of *concrete* physical features (e.g., objects and their interactions) and *symbolic* representations (e.g., coordinate systems) to make sense of and model physical scenarios. Using interaction analysis, we illustrate how students can laminate these different layers of abstraction together in gesture to generate complex explanations to solve physics problems. We argue that laminating different layers of abstraction (both the symbolic and concrete) constitute a key form of representational competence in physics.

Introduction

Representational gestures that capture iconic, spatial information about the world are important tools for sense-making in science (e.g., Scopelitis et al., 2010) that both physicists (e.g., Ochs et al., 1996) and physics students (e.g., Scherr, 2008) routinely use. Representing ideas with gesture allows students to re-create dynamic, three-dimensional features of processes or entities that can easily be altered or revised as needed. There are many ways students can use gestures to model and explain scientific and mathematical ideas. For example, students might adopt different points of view in their gestures (e.g., taking a first-person point of view of throwing a ball vs. taking a third person point of view tracing the path of a ball; DeLiema et al., 2021). Students may also choose to use gesture to illustrate ideas or topics by representing symbolic features (e.g., crossing two fingers perpendicularly to make a symbol for addition) or more physical and concrete features (e.g., using two hands to show two imaginary piles added together; Alameh et al., 2016). Chase & Wittmann (2013) demonstrated how students use gestures to represent multiple characteristics of physical scenarios (e.g., showing increasing velocity while also tracing the trajectory of a projectile).

In this study, inspired by this prior work, we examine how physics students use complex sequences of representational gesture in explanations that *simultaneously* bring together and merge both abstract, symbolic features (e.g., coordinate systems, mathematical representations) as well as concrete depictions of physical scenarios (e.g., illustrating the movement and interactions of physical objects). We develop a framework for explaining how students laminate layers of abstraction and provide an example analyzed in-depth.

Theoretical framework: Representational competence and lamination

Knowledge in physics is produced by modeling and representing physical scenarios using various tools and conventions. These include specific types of mathematical notation, coordinate systems, graphs, measurements, and specialized data visualizations. Learning physics requires students to develop *representational competence* and be able to use these tools and conventions flexibly and fluidly. At its core, representational fluency refers to capturing ideas through different means of “external visualization” and includes gesture (Lira & Stieff, 2018).

When people communicate with each other in everyday interactions, they often layer together different types of semiotic resources such as gestures, speech, and prosody (the melody of speech) to produce utterances (Goodwin, 2018). Goodwin termed this process *lamination*. We note that when students explain ideas and scenarios in physics, they must represent physical and directly observable processes and characteristics and connect them with symbolic and conventional forms of external representation, specific to the scientific practice of physics. We argue that gesture provides a unique medium for *laminating* together these two different layers of abstraction in physics explanations. That is, a student can use gestures to merge together physical and symbolic features of the explanation. We propose that laminating different layers of abstraction – both the symbolic and the concrete – together in gesture during multimodal physics explanations constitutes an important and overlooked form of representational competence in physics.

Methodology and background

This present study of laminated layers of abstraction emerged from a broader project to document diverse ways undergraduate physics students use representational gestures during collaborative problem solving in physics. We are working with a video corpus collected at a large university of an algebra-based *Collaborative Learning through Active Sense-making in Physics* (CLASP) course where groups of 2-4 students worked through problems

involving mechanical energy transfers and transformations. Representational gestures were coded for 11 groups of students working on 6 problems. From this initial collection of representational gestures, we noticed how students often laminate *symbolic* and *concrete* representational features while modeling phenomena. We collected and investigated sequences containing representational gestures with both symbolic and concrete features using the micronanalysis of interaction (Goodwin, 2018). We conducted group analysis to verify our interpretations of what aspects of the problem were being represented through gesture in each case. We selected the case we present in this preliminary paper as a clear, representative, and demonstrative example of this phenomenon.

Laminating concrete and symbolic representations in gesture

The physics problem: Tossing a ball up into the air

A person throws a ball straight up with some initial velocity from a certain height (h) above the floor. The ball then reaches a maximum height ($h_{\max}$) above the floor before it falls back down. Students are asked to model this scenario in two different ways to determine whether the *maximum height above the floor* that the ball reaches *changes* if a different reference point is used to determine the position of the ball. First, students must create a model where they measure the location of the maximum position of the ball with respect to the floor, i.e., students are to assume that the *origin* of the coordinate system – where the vertical position of the ball y is equal to 0 – is at floor level. In a second step, students are supposed to assign the coordinate system origin ($y = 0$) to the position where the person's hand releases the ball (at height h above the floor) and determine the location of the highest point the ball reaches with respect to the release position.

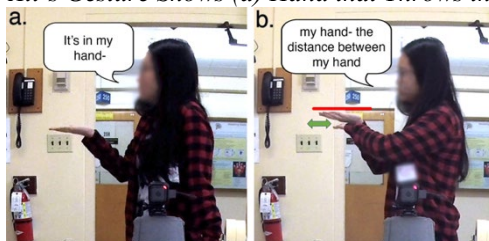
Students model the energy dynamics by sketching the path of the ball and deriving a mathematical description of energy conservation to determine the maximum height above the floor of the ball. Using their sketch, students identify indicators for changes in energy forms, like the change in vertical position (or *displacement* Δy) of the ball from the location of the hand to the highest point above the ground (indicating an increase in gravitational potential energy PE of the ball), and the change in velocity from the initial speed the ball has when leaving the hand to zero when it reaches its highest point (indicating a decrease in kinetic energy KE associated with the *motion* of the ball). KE decreases as much as PE increases, so students can use their mathematical description of energy conservation to determine the vertical displacement Δy of the ball. To find the maximum height of the ball above the floor, they add this change in vertical position to the original launch height above ground (h): $h_{\max} = h + \Delta y$. Notably, the models result in exactly the same mathematical description of energy conservation because they both depend on *changes* in indicators, and not the particular values of these indicators at a given point in time as measured in a particular coordinate system. Thus, both models will yield the same value for the displacement Δy and therefore the maximum height $h_{\max}$ above the ground that the ball will reach.

Ali's proposal for solving the physics problem

We present the case of Ali's proposed explanation for why the maximum height of the ball would be the same, regardless of the chosen coordinate system. Ali uses a complex gesture with multiple parts to laminate together different layers of abstraction as she explains her rationale to her groupmates. Ali's gesture also demonstrates her understanding of the situation and her representational competence by laminating both symbolic and concrete representations. We analyze this gesture in six parts (a through f) which we illustrate with Figures 1-3.

Figure 1

Ali's Gesture Shows (a) Hand that Throws the Ball and (b) Initial Position.

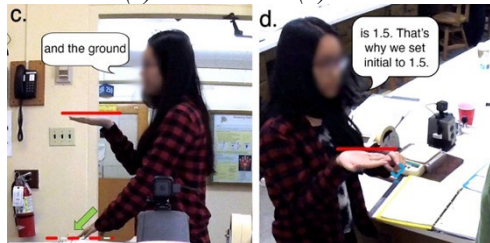


Ali starts by using her right hand to illustrate the *ball in a hand* from the problem (Figure 1a). This is a *concrete representation* that invokes two physical elements of the problem: the hand and the ball. From this representation, there is information about the orientation of these objects (e.g., a “palm up” hand) and how they are interacting (the imaginary ball *is in* the hand). Ali uses this concrete representation as an anchor to layer both new concrete and symbolic imagery onto. Next, Ali slides her left hand underneath the right hand, tracing a line,

depicting the abstract idea of an *initial position* (Figure 1b). By creating this imaginary “underline,” she evokes the image of an abstract, *symbolic representational* feature: lines are commonly used to indicate initial positions and reference points in physics diagrams. This initial position line has now been overlaid over the concrete image of the hand with the ball.

Figure 2

Ali Shows (c) Ground and (d) Distance between Ground and Initial Position.



After establishing the presence of a hand and an initial position (Figure 1), Ali then drops her left hand and points to the floor she is standing on to introduce the *ground* into the explanation of the scenario (Figure 2c). Like the hand “being a hand,” invoking the *actual* ground and adding it to the imagery generates another *concrete representational characteristic* for the explained scenario. Next, Ali adds a second *symbolic representation* in gesture: She makes a pinch shape with her left hand to illustrate the *distance* between the ground and the hand/initial position that she describes as 1.5 meters (Figure 2d).

Figure 3

Ali Shows Maximum Height the Ball Reaches with Respect to Ground.

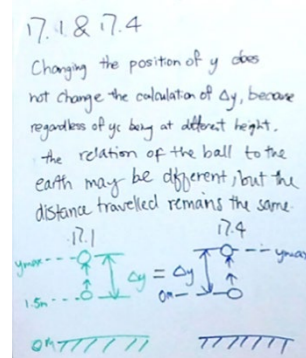
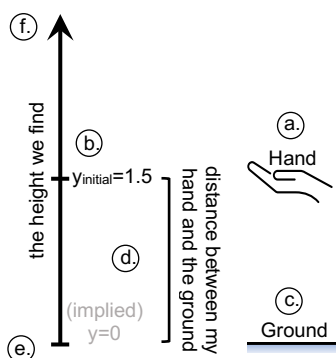


In the last part of her gesture, Ali lowers her left hand toward the floor (Figure 3e) and then raises it up through and past the initial position to her forehead level (Figure 3f). Tracing this measurement provides a *symbolic* representation of the maximum height that the ball will reach above the ground.

Throughout her entire gesture, Ali keeps her right hand in place with the ground below (*concrete* representations) and laminates different *symbolic* representations (initial position, distance of hand from floor, maximum height of ball) onto this anchor to define and clarify why the maximum height of the ball above the floor remains the same, regardless of the different reference points ($y = 0$ at the floor vs. at the release position).

Figure 4

Left: Schematic Illustration of Ali's Gesture Explaining the Scenario. Letters Correspond to Pictures above for each Gesture Component. Right: Group's Final Answer on the Whiteboard.



Concluding remarks

Ali models the physical scenario productively by laminating symbolic and concrete features through a complex, multi-part gesture (Figure 4, left). After Ali's proposal and explanation, the group continues to correctly conclude that the maximum height of the ball above ground remains the same, regardless of the chosen reference point and y-value of the release point in their models. In Figure 4 (right), we present the final solution captured on the group's shared whiteboard. The diagram mirrors Ali's merged use of concrete and symbolic representations, but not verbatim: The concrete hand is not included, but a ball and the ground are drawn. Initial and max positions are included as symbolic representations, as are two representations of the vertical displacement Δy .

Representational gesture is an underappreciated form of representational competence. The complex, dynamic, and abstract phenomena of physics require both concrete and symbolic forms of representation to model physical scenarios and solve problems. Symbolic and concrete depictions help students break problems down into discrete layers. Representational gestures can glue these layers together to construct a complete model of the problem. These gestures can also help students develop explanations even in the absence of a fully developed mastery of symbolic conventions and technical vocabulary (Roth & Welzel, 2001).

Our exploration of *laminated layers of abstraction* in physics gestures supports and contributes to previous literature on gesture in physics (Scherr, 2008), the use of gesture to blend features of physics phenomena (Chase & Wittmann, 2012), and the use of gesture to represent either symbolic or concrete features of science and mathematics ideas (Alameh et al., 2016). We conjecture that laminated gestures play a particularly important role in collaborative problem solving and modeling in physics group work. While our study is preliminary, in future work, we will attempt to (1) identify and characterize more ways students laminate layers of abstraction in gesture when solving problems together and (2) investigate whether there is any relationship between students' use of gesture with laminated abstraction and groups' problem-solving outcomes. Previous work (Alameh et al., 2016) found that middle school students who use strictly symbolic representations in their gestures demonstrated lower levels of conceptual understanding. Alternatively, an inference we make about undergraduate physics is that laminated layers of abstraction in gesture may allow students to construct more versatile and productive models.

Although still in early stages, our investigation of how physics students laminate together different levels of abstraction (both symbolic and concrete) in gesture suggests possible implications for teaching and learning. Instructors may be able to identify students that are struggling to imagine various physical scenarios if their gestures appear to be entirely symbolic, and students that are struggling to apply physics models if their gestures appear to be entirely concrete. Encouraging students to use gesture to illustrate and make sense of both concrete and symbolic aspects of physics problems may support students' modeling and problem solving. Further, encouraging students to attend to and build on each other's concrete and symbolic gestures (for example, adding a symbolic feature to a concrete gesture or vice versa) may also enhance collaborative sense-making processes.

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Acknowledgments

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