

Differentiation Of Energy Concepts Through Speech And Gesture In Interaction

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Abstract. Through the microanalysis of one interaction between learners (in a course on energy for in-service teachers), we observe the coherent states of conceptual differentiation of different learners. By attending to details of how the learners interact with each other across this developmental gap, we aim ultimately to better understand how conceptual development happens in interactive learning and how it might be accomplished more effectively.

Keywords: energy, embodied cognition, gesture, conceptual development, interaction.

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INTRODUCTION

We closely analyze one interaction between learners (in a course for in-service teachers) in which each learner exhibits one of two coherent states of conceptual refinement about energy. By attending to details of how the learners interact with each other across this developmental gap, we aim ultimately to better understand how conceptual development happens in interactive learning and how it might be accomplished more effectively.

THEORETICAL PERSPECTIVE

Our theoretical perspective includes a model for conceptual development and the relationship of that model to embodied action in human interactions.

Differentiation And Integration In Conceptual Development

We take the view in this study that learning can be understood as a process of learners alternating fluidly between the processes of differentiation and integration [1] to restructure their knowledge. In differentiation, learners develop sustained awareness of fine structure within a more general structure. For example, physics students ideally become more aware of how *motion* may be understood in terms of the more refined ideas *velocity*, *acceleration*, etc. In integration, abstract features of finer structures may be creatively synthesized to form a new, more complex structure. For example, students may use an object's instantaneous velocity and acceleration vectors together to determine the local shape of the trajectory and the rate at which the speed is changing. In this case, the already differentiated concepts of velocity

and acceleration are not only held in mutual contrast; they are also coordinated precisely and asymmetrically in a way that yields new knowledge.

Gesture As A Learning Tool In Interaction

Studies on the interactive learning practices of scientists [2] and physics students [3] show the importance of gesture as one among many channels along which knowledge and meaning are communicated and fields in which they are constructed. In this analysis, we emphasize gesture (along with speech) because of its high levels of flexibility, availability to learners, and the value afforded for understanding spatial aspects of physics.

We provisionally synthesize our understanding of differentiation and integration with our view of the multi-modal nature of interaction through the idea that the abstract cognitive processes of *concept* differentiation and integration are mechanistically facilitated by the differentiation and integration of real *actions* in speech, gesture, and other media.

DATA SOURCES AND METHODS

Data and methods for this study follow the tradition of fine-grained, qualitative, multi-modal interaction analysis [4]. Our primary source of data is video records of interactions between learners during an interaction-rich learning situation. Throughout initial review of the records, we identify episodes during which something significant seems to have happened for the participants. These moments often include arguments or other animated discussions in which learners' ideas are richly communicated to others or the cognitive dynamics are relatively externalized. After identifying an episode for more careful analysis,

we study the development of knowledge and learning in that situation. Our primary guide for interpreting the meaning of speech, gesture, and other actions in the situation is the immediately prior interactive function of any similar actions within the situation.

CONTEXT OF LEARNING SITUATION

Energy Course For Teachers

The teachers in this episode were enrolled in the second year of a two-year sequence of intensive summer courses on the learning and teaching of energy [5, 6]. Each course lasted ten full days. The episode analyzed here occurred on the eighth day, after about eight hours (over three days) of intensive small-group-directed study of refrigerators using information from the internet. The teachers were challenged to develop a narrative of the energy transfers and transformations in a household refrigerator.

Background: Physics Of Refrigerators

An introduction to refrigerators usually focuses on the overall transport of energy in terms of the work W supplied externally to the refrigerator, the heat Q_C extracted from the cold reservoir, and the heat Q_H delivered to the hot reservoir [7]. This treatment allows students the opportunity to understand how W , Q_C , and Q_H are mutually constrained by the first and second laws of thermodynamics, but it does not invite students to understand the mechanisms involved in real refrigerators, including the crucial role of the gas-liquid phase transition of the refrigerant.

The vapor compression cycle that is used in most household refrigerators involves four major components: evaporator, compressor, condenser, and metering device. As the refrigerant circulates through the sealed system, it moves from one component to the next, in the above order, changing phase between liquid and gas, and exchanging energy with its surroundings through a variety of mechanisms.

We limit our present analysis of the energy in the vapor compression cycle to that in the evaporator. In the evaporator, which is a long, winding tube in thermal contact with the contents of the refrigerator ("food"), the refrigerant is a very cold mixture of liquid and gas. Throughout the evaporator, the refrigerant is colder than the food. Because of this temperature difference, energy flows from the food to the refrigerant. When the energy is received by the refrigerant, its resulting change in physical state is not an increase in temperature but an increase in the proportion of gas in the liquid-gas mixture. Our teachers' commitment to the framework set forth in

the Benchmarks for Science Literacy [8] required the invention of a distinct form of energy, since the newly received energy cannot be *thermal energy*, which is tied directly to temperature. Teachers in our episode ultimately decided to call this *phase energy*.

MOLECULES EPISODE

We analyze speech and gestures in the interactions in a group of teachers in the following episode.

Actions In The Molecules Episode

In this episode, twelve participants were present and five spoke, but we analyze the actions of only the three major participants: Donna, Beth, and Mark. The episode analyzed here is 21 seconds long.

The following transcript is tagged with numerical labels to indicate gestures by the speakers. The tags are placed at the end of the phrase during which the gesture occurred. (D, B, M, S, and J are Donna, Beth, Mark, Sarah, and Jack.) The initial *it* refers to the form of energy increasing in the evaporator.

D: It's different from thermal
B: Is it really? I mean
J: It really, it could be a, it's, it's
D: It's different than average kinetic energy of the molecules.
M: Yeah!
S: Right.
D: When you're changing phase, that's different from the average thermal energy.
B: Because it
S: It should be different.
B: When you're changing phase (1), you're making the molecules (2) either move way more (3)
M: They're moved farther apart (4) but the molecules aren't moving faster. (5)
B: Farther apart. (6)
D: You're changing the positions (7) but they might be vibrating the same amount (8)
B: Oh...Oh, I see what you're saying.
D: So the average kinetic energy is... could still be the same (9)
B: 'Cause it's the same, it's just farther apart (10).
D: It's a change in the potential, because it's a change in the positions (11).

Description Of Labeled Gestures

(1) Beth's palms face each other, and her fingers on each hand diverge and are slightly curled, in the shape of a spherical cap. (See "cap" in Fig. 1.) She shakes her hands forward once. (2) Beth rapidly pulses her hands laterally outward twice, expanding

the spacing between her fingers with each pulse, as if the sphere her hands are capping has a rapidly expanding and contracting radius. (3) Beth continues the expansion gesture once so that it becomes as large as her body. This motion is smooth in time and linear in space. (4) Mark's hands are in front of his shoulders. His palms are facing each other, his fingers are parallel, leaving no space in between. His fingers are perpendicular to the palm at the base of the fingers (see "bracket" in Fig. 1). He uses his hands to make a laterally outward bouncing gesture, with the "impact" part of the bounce on the syllables *far* and *part*. The length of the bounce on each side is about 20 cm, and its height is about 5 cm. (5) Mark's hands rapidly change shape in mid-sentence to the "fist" shape in Fig. 1. His puts his fists side-by-side and shakes them forward and back about six times. (6) Beth's hands are now bracket-shaped but the motion is smooth and linear as in gesture 3. (7) Donna quickly takes her fist-shaped hands laterally out to about $\frac{3}{4}$ arm's length. (8, 9) Donna's fists shake back and forth continuously throughout her speech, at about $\frac{1}{2}$ arm's length. (10) Beth repeats gesture 3. (11) Donna's fists bounce laterally in and out three times as in Mark's gesture 4, but with a greater bounce length of about 40 cm.

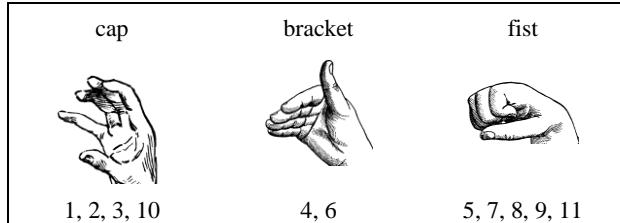


FIGURE 1. Hand shapes used in gestures 1-11. [9]

Coherent States Of Conceptual Differentiation

We use evidence from speech and gesture to show how Beth, Mark, and Donna each exhibit coherent states of conceptual differentiation relating to the energy of evaporation. Mark and Donna differentiate two concepts (which we label *kinetic* and *configurational*) that are, for Beth, one undifferentiated concept (*scaling*) (See Fig. 2.a.). We present kinetic and configurational as not exclusively microscopic concepts but with the idea that each has microscopic and macroscopic components.

Beth is openly skeptical about the group's suggestion that the energy of evaporated gas should be notated differently from "thermal energy," which has been used previously by the group to correspond to the temperature. The prosody of her question "Is it really?" with its pattern of falling pitch is more

rhetorical than inquisitive. In addition, prior to the episode transcribed above, Beth states repeatedly that "we just called it thermal energy" and that "it's still thermal energy, though, isn't it?" In contrast, both Mark and Donna affirm the importance of noting that the energy in question is "different from thermal." Mark also observes shortly prior to this that "you guys are not increasing the temperature, you're changing the phase." With this parallel grammar, Mark not only notes each fact but presents them in a way that highlights the contrast.

Beth's statement "you're making the molecules either move way more" shows a lack of differentiation between objects moving with a greater average speed or moving at a greater average distance or separation. It is unclear from the point of view of formal physics concepts whether the idea of something "moving more" refers to a dynamic increase in speed or a comparative relocation to a greater distance. In contrast, both Donna and Mark use vocabulary that clearly distinguishes one concept from the other. Mark says *apart* and *faster*; Donna says *positions*, *vibrating*, *kinetic*, and *potential*. Donna's grammar also shows whether words are associated with similar or opposite concepts. For example, *potential* and *positions* go together because their grammatical functions are similar in her final turn.

Beth's initial gesture of expansion shows outward motion that does not distinguish motion *per se* from a difference in location. That is, it is not clear from her gesture whether the motion itself of her hands symbolizes the actual dynamical trajectory of something (the gas or its constituent particles) or is only somatically necessary to compare two locations. Mark and Donna, however, both clearly distinguish dynamical motion from comparing locations; they each use a shaking motion to show how molecules move in time, and they use the lateral bouncing motion not to indicate how the molecules move but how the spacing of molecules in a gas and a liquid are different.

Dynamics Of Failed Differentiation

In addition to showing what each person thinks about evaporation, these actions also show what Mark and Donna think about Beth's understanding. They diagnose correctly (we think) that Beth has not differentiated two ideas that they have. Their actions immediately respond to hers and are directed spatially at her, as though their actions are intended to help her achieve the same state of differentiation (Fig. 2.b.). The bracket shape of Beth's gesture 6 and her words *farther apart* show that she hears and sees what Mark is saying, since these details of his expression are

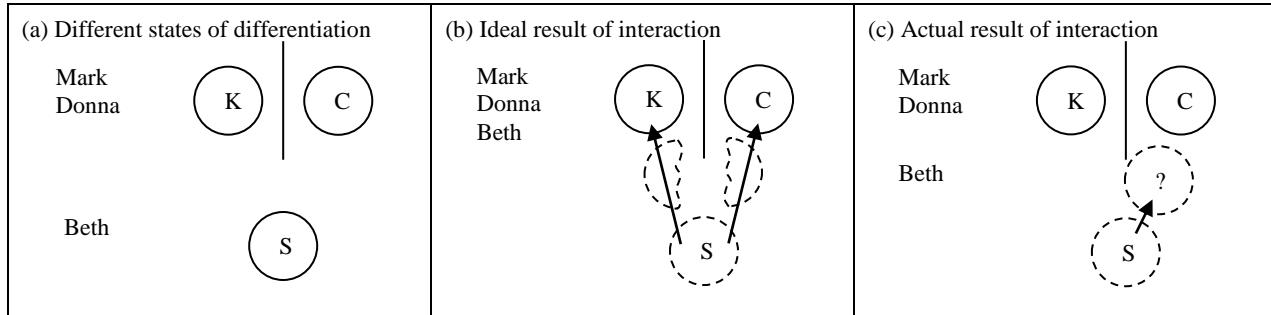


FIGURE 2. Schematic diagram of different states of conceptual differentiation. a) Mark and Donna differentiate the concepts *kinetic* (labeled K above) and *configurational* (C). Beth's concept *scaling* (S) fuses (rather than coordinates) elements of kinetic and configurational. (b) When Mark and Donna observe Beth's undifferentiated actions, they correct her with differentiated actions. The ideal result of this correction is that Beth's concept S will become differentiated into K and C. (c) The actual result of the correction in this interaction is that Beth's actions become more like those associated with C, but with no explicit acknowledgement of K.

immediately repeated by her. This change might indicate the beginning of a process of conceptual differentiation for Beth. However, she does not repeat the fist shape or the bouncing and shaking movements, and does not repeat any of the other words that Mark and Donna use to differentiate the kinetic and configurational concepts. The fact that the two active elements she does pick up (the bracket hand shape and the words *farther apart*) both belong to the configurational concept suggests that her scaling concept might be understood as moving toward the configurational concept but still not differentiating in relation to kinetic. We interpret Beth's initial use of *thermal* not as belonging properly to the kinetic concept, the way it would perhaps for Mark and Donna, but functioning more as a placeholder word in Beth's understanding of the energy related to heating in general. Finally, the fact that Beth's gesture 10 more closely resembles gesture 3 than it does gesture 6 might indicate a regression in the differentiation process.

Thus, overall, Mark and Donna's intervention fails (on this time scale) because Beth's concept appears to remain undifferentiated. However, we believe that Beth's immediate duplication of some elements of Mark's speech and gesture indicates the promise of using explicitly differentiated action in instruction to facilitate a concept differentiation process.

CONCLUSION

The example interaction analyzed here illustrates how detailed analysis of speech and gesture of learners can yield descriptions of different coherent states of conceptual differentiation. The interaction between learners of different coherent states suggests that the clearly differentiated speech and gesture by a speaker is not in itself sufficient to accomplish conceptual differentiation for the hearer. The real-time receptivity

of the hearer to novel actions shows some promise for instructional interventions founded in the learning of differentiated concrete action in speech and gesture.

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