Student behavior and epistemological framing:
Examples from collaborative active-learning activities in physics

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Abstract: Questions of participant understanding of the nature of an activity have been addressed in anthropology and sociolinguistics with the concepts of *frames* and *framing*. For example, a student may frame a learning activity as an opportunity for sensemaking or as an assignment to fill out a worksheet. The student's understanding of the nature of the activity affects what she notices, what knowledge she accesses, and how she thinks to act. Previous analyses have found evidence of framing primarily in linguistic markers associated with speech acts. In this paper, we show that there is useful evidence of framing in easily observed features of students' behavior. More broadly, we describe a dynamic among behavior, framing, and the conceptual substance of student reasoning in the context of collaborative active-learning activities in an introductory university physics course.

Introduction

Large college physics courses are especially challenging settings for physics instruction. Among the challenges is the difficulty of providing opportunities for student discussion of physics concepts. For about twenty years, reform-minded physics professors have been using "tutorials" (McDermott, Shaffer, & the Physics Education Group at the University of Washington, 1998), worksheets that guide collaborative active learning in small groups around core conceptual issues identified by research as essential for students to address. Tutorials can be implemented as a relatively small modification of the conventional lecture-based course, and there is now a substantial body of evidence they lead to substantial improvement in students' conceptual understanding (Redish & McDermott, 1999).

That evidence, however, is almost exclusively in the form of pre- and post-testing with qualitative and quantitative examinations. While gains in student scores support researchers' conjectures regarding what contributes to student learning, there has been little direct investigation of what happens during the instructional activities. Meanwhile, these curricula have not led to corresponding gains in scores on measures of student expectations and epistemologies — how students understand what knowledge, reasoning, and learning in physics entail. In fact, students in most introductory courses, including those that use tutorials, tend to come away with evidently less sophisticated views of knowledge and learning in physics courses (Redish, Saul, & Steinberg, 1998). This seems discrepant: Shouldn't students who are apparently more successful at learning also become more aware of what successful learning entails? Why would experiences that improve conceptual understanding lead to "deterioration" (Redish et al., 1998) of expectations?

There are several possibilities, some of which give cause for concern. One is that students come to see introductory physics as detached from everyday experience: surveys at the end of every course in Redish et al.'s (1998) study indicated students saw physics as less connected to their experience than they did at the start. Another possibility is that student epistemologies as measured by an explicit survey do not reflect their epistemologies in contexts of reasoning within the course; responding to a survey is a very different context from reasoning about physical phenomena (Hammer, 1994). Perhaps students' "practical epistemologies" (Sandoval, 2005) come to be more sophisticated than the survey detects.

The possibly problematic relationship between students' conceptual and epistemological learning motivates us to study students' work during tutorials in detail. In particular, we hope to learn how they understand the activity of tutorials with respect to knowledge, reasoning, and learning. What are their perceptions of its goals, and what methods do they believe will serve them best? In other words, as we elaborate below, we are interested to study students' *epistemological framing* of the activity. To address the possibility of contextual dependence, we study their work *in situ*, rather than interrupting it with a survey or specialized interview.

At the start of this study, the first author set out to formulate a systematic observational protocol: what could we look for in the video data as evidence of how students understand the activity? Initial exploration of video data led to the discovery of four distinct patterns of the students' physical behavior. In some segments of video, for example, the students are bent over their worksheets, talking in subdued voices with their hands relatively still; in other segments, they are sitting up straight, looking at each other, speaking in loud voices, and gesturing prolifically. These clusters of co-occurring behaviors stand out clearly; having had them described, and with very little training, independent coders achieve 95% agreement in classifying 5-second video segments into one of four clusters.

Our purpose in this paper is to argue that these different behavioral clusters are evidence of — and in dynamic interaction with — student epistemologies. Roughly, we will show, the behavioral cluster of sitting up, speaking clearly and gesturing supports and is supported by a framing of the activity as discussing each others' conceptual ideas. In this way, we hope to contribute to research methodology for the study of student learning, and specifically students' epistemological framing. As well, we discuss how this work furthers a resource-based account of knowledge, reasoning, and learning.

Theoretical framework
Epistemological framing

Framing is a construct developed in anthropology and linguistics (1) to describe how an individual or group forms a sense of "What is it that's going on here?" (Bateson, 1972; Goffman, 1986; MacLachlan & Reid, 1994; Tannen, 1993) To frame an event, utterance, or situation in a particular way is to interpret it based on previous experience: to bring to bear a structure of expectations about a situation regarding what could happen, what portions of the information available to the senses require attention, and what might be appropriate action. For example, monkeys engaged in biting each other are skilled at quickly and tacitly "deciding" whether the biting is aggression or play (Bateson, 1972). An employee may frame a gift from her supervisor as kind attention or as unwelcome charity. A student may frame a physics problem as an opportunity for sensemaking or as an occasion for rote use of formulas.

In school settings, epistemological framing is of particular importance: students form a sense of what is taking place with respect to knowledge, including, for example, what portions of information and experience are relevant for completing assignments. Other aspects of framing are important as well, including social framing, in which students form a sense of what to expect of each other, of their instructor, and of themselves. For groups of students working together collaboratively, different aspects of framing interact.

Previous analyses have found evidence of framing primarily in linguistic markers associated with speech acts (2). Nonetheless, because frames "emerge in and are constituted by verbal and nonverbal interaction" (Tannen, 1993, p. 60), evidence of framing can come in a variety of forms. In our work we have found a wealth of paraverbal and nonverbal cues of framing, and so have focused on those cues in addition to linguistic markers. In any social interaction, framing presents a communicative task in which participants collaboratively establish the nature of their shared activity. Conversational partners both indicate the nature of the activity they're engaged in by means of verbal and nonverbal interactions, and observe others' behavior in order to learn what kind of activity is taking place. If a speaker makes eye contact, gestures while speaking, and uses an animated voice, she is both experiencing an engaged discussion herself and displaying to others that they are mutually engaged in a discussion (3). Participants interpret one another's signals regarding the nature of the activity by means of contextualizing cues that include body language (*e.g.,* facial expression, gesture, and posture), prosodic features of utterances (*e.g.,* pitch variation, loudness, pausing, pacing), and linguistic signals (choice of vocabulary, levels of formality, choice of pronouns) (Goodwin, 2000; Tannen, 1993, p. 62). The task of this paper is to articulate a dynamic between readily observable behavior and epistemological framing, which we suggest has methodological and theoretical implications for research. In the following section we summarize the general view of cognitive structure and intuitive epistemologies that underlies this work. We then turn to examples of behavioral analysis of students' work in tutorials.

A resource model of epistemologies

This work takes place within a larger program of research to develop resource-based models of knowledge and reasoning in physics (Hammer, 2000; Redish, 2004; Scherr, 2007), in line with diSessa's (1993) model of intuitive physics as made up of fine-grained, context sensitive "phenomenological primitives" and, more generally, with Minsky's (1986) model of mind as consisting of manifold cognitive "agents." Hammer and Elby (2002) proposed modeling intuitive epistemologies in terms of epistemological resources, rather than using beliefs, theories or stages of development as the units of cognitive structure. That is, rather than attributing unitary epistemologies to students, such as that knowledge is received from authority, certain, or simple (see review in Hofer & Pintrich (Eds.), 2002), this view attributes a variety of resources for thinking about knowledge in different ways at different times. From early ages, students have resources for thinking of knowledge as received, as inferred from other knowledge, as invented or as perceived. They have resources as well for understanding a wide variety of kinds of knowledge, epistemic activities, and stances—facts, stories, lists, rules, suppositions, doubt, certainty, and so on—resources they may activate or not depending on the particular situation. Thus a resource-based view of epistemologies accounts for the variability and multiple coherences in student reasoning, as evident in studies focused on individual students across different contexts (Knight & Sweeney, under review; Leach, Millar, Ryder, & Sere, 2000; Lising & Elby, 2005) and on groups or classes (Louca, Elby, Hammer, & Kagey, 2004; Rosenberg, Hammer, & Phelan, 2006; Roth & Roychoudhury, 1994; Sandoval, 2003).

Redish (2004) proposed the idea of *epistemological frames* to connect this work to the construct of framing in linguistics and anthropology. At the level of resources, we take a frame to be a locally coherent pattern of activations – "coherent" in that the pattern holds together for some length of time and "local" in that the coherence may be particular to the moment or context (Hammer, Elby, Scherr & Redish, 2005). This is a dynamic systems account of framing; coherences emerge from the activations and interactions of many cognitive elements. They may involve resources within an individual's mind or across multiple individuals or a group. Framing is defined in the literature in terms of individual reasoning (Tannen, 1993) and of social dynamics (Goffman, 1986); a resource-based model of framing allows theoretical continuity between the two, that is, between cognitive and discourse dynamics (Brown & Hammer, in press).

The analyses that follow expose portions of the dynamics of resources and framing as they operate among groups of four students working in tutorials. They show, in particular, how physical behavior may play a role in those dynamics, such that observations of physical behavior can provide evidence of epistemological framing.

Context for Research

The tutorials took place as part of a two-semester algebra-based introductory physics course at the University of Maryland, with 160 students in each lecture section, most of whom are junior and senior health and life science majors. More than half are female and there is wide ethnic diversity reflecting the student population of the University of Maryland. In this course, the traditional TA-led recitation was replaced with worksheet-based group-learning activities ("tutorials") based on the model developed at the University of Washington (McDermott et al., 1998; McDermott, Shaffer, & Somers, 1994). In the tutorial sessions, students worked in small groups on worksheets that led them to make predictions and compare various lines of reasoning in order to build an understanding of basic concepts. Teaching assistants (TAs) served as facilitators rather than as lecturers: instead of demonstrating problem solutions to students, they engaged the students in discussions of difficult concepts. Each class section consisted of five groups of four students each, supervised by two TAs. For the study reported in this paper, we selected a group that was videotaped working through a tutorial on Newton's third law.

Identifying and Interpreting Behavioral Clusters

As mentioned in the introduction, we have found four distinct patterns of students' physical behavior in the data for this study. In what follows we present the method we used to identify these behavioral clusters and the content of each of the four clusters that we identified.

Methodology

In order to identify clusters of behaviors that appear in our data set, coders independently watch video of small groups of students and note the exact time of *changes in* the students' vocal register, affect, grammar, gesture production, and body language. Having noted changes in behavioral clusters, we then systematically identify the features of the behavioral cluster: hand motions including gestures (Goldin-Meadow, 2003), facial aspect, body position and/or movement, vocal register, gaze, and so on. We label the behavioral clusters with meaning-neutral labels (colors). Identifying the behaviors within each cluster permits coders to reliably observe when students participate again in a behavioral cluster the coder had previously identified (*e.g.,* shift back into a certain cluster after engaging in other behaviors).

Coding is performed in real time without transcript. At least two researchers code the changes independently. Tannen's (1993) research led us to expect that clusters of behaviors typically change all at once for an entire group of participants, and that is generally the case in our data. Coders are able to code the whole group reliably (peers typically share the same behavioral cluster (4)). The behavioral clusters are distinct and easy to identify, with 95% inter-rater reliability before discussion, to five seconds' accuracy.

Behavioral clusters defined

In the behavioral cluster that we have labeled "blue," students' eyes are primarily on their papers with brief glances up at their peers. Their bodies lean forward at an angle of about 30° to the vertical, their hands are mainly at rest (few gestures), and their faces are relatively neutral. Their tone of voice is low, quiet, and indistinct, and their speech consists largely of phrases read from their worksheets; when they speak to one another, they briefly and quietly speak with rising intonation, and answer briefly and quietly with falling intonation. The initiator often utters an incomplete sentence that is completed by a peer.

In the "green" behavioral cluster, students sit straight up and make frequent eye contact with one another. Their faces and voices are animated; they gesture relatively prolifically and engage in clear, loud, original speech.

The "red" and "yellow" behavioral clusters do not appear in the excerpt we analyze in detail below, but we describe them briefly here for completeness. The "red" behavioral cluster involves the students' interaction with a teaching assistant, although students need not exhibit the red behavioral cluster all the time that a TA is present (5). The students speak little and make eye contact with the TA. They sit straight with their bodies still, and their hands are relatively quiet except for habitual movements.

In the "yellow" behavioral cluster, students giggle or smile, and have hedging or joking tones of voice. They shift their bodies around in their seats and touch their own faces and hair. Their gaze is unsettled, moving among peers, papers, and other points in the room. The yellow behavioral cluster appears to be somewhat less stable than other three clusters identified in our examples: although it recurs regularly, it rarely lasts even as much as thirty seconds, whereas the other three clusters often persist for minutes at a time.

Behavioral clusters interpreted

We coded the behavioral clusters by colors, in an attempt to suspend our inclinations to interpret them while we defined the specific physical behaviors involved. Having arrived at these definitions and shown inter-rater reliability, we shifted to interpretation; what do these different behavioral clusters suggest with respect to epistemological framing? For us, as we expect for the students, this interpretation is automatic and unconscious—it is difficult not to do it. That is reason for attending to it systematically in analyzing student thinking.

The behaviors associated with the blue and green behavioral clusters indicate very different framings of the tutorial activity, in spite of the fact that both might loosely be called "working collaboratively on the tutorial." In the blue behavioral cluster, the fact that students' eyes are on their papers and their bodies lean over the desks sends the message that their main interaction is with the worksheet. Students' neutral facial expressions and lack of gestures further suggest that they expect minimal interaction with their peers; the tutorial activity is, apparently, primarily expected to be individual at this point. They do glance occasionally at one another, indicating an expectation of "check-ins" with peers from time to time, and they read aloud, indicating that they expect their partners to coordinate with them. The reading aloud, however, is indistinct, indicating that they expect their peers are already reading the same thing on their own. The students evidently frame the activity as primarily *completing the tutorial worksheet.*

The green behavioral cluster, on the other hand, is characterized by original speech delivered in relatively loud, animated voices, indicating intellectual and/or emotional engagement. Sitting up straight and making eye contact with one another, students display an expectation that their attention belongs on their peers. Their clear speech and prolific gestures indicate further that they expect their peers to pay attention not only to the fact that they're talking, but to the details of what they're trying to express. Watching students behave in this way, we understand them and they understand each other to be engaged in a *discussion.*

In the red cluster, similarly, students display expectations that their attention belongs on the TA, suggesting that they frame the activity as *listening to the TA.* The behaviors associated with the yellow behavioral cluster are less straightforward to interpret than those of the other clusters: on the one hand, they seem to indicate social discomfort or perceived vulnerability (students avoid direct eye contact, fidget in their seats, and fiddle with objects), while on the other hand, they laugh, smile, and appear to joke with one another, behavior that indicates play. These characterizations are not mutually exclusive; play is a "nonliteral orientation" (Tannen, 1993, p. 114) that may be initiated as a cover for actions involving some personal risk. We refer to the frame indicated by the yellow behavioral cluster as the *joking frame* to include the sense that students are signaling that the content of their speech should not be taken literally (even though they may also intend, on some level, to explore the ideas that they express).

Analysis of student behavior and epistemological framing

In what follows we describe in detail some of the shifts in behavioral clusters that we observed in our analysis of the selected group and tutorial, and we show that those shifts correspond to shifts in the substance of students' reasoning as evident in their speech and gestures. Taken together, the students' behavior, speech and gestures support interpretations of the students' epistemological framing.

In the first three minutes of working actively on the tutorial worksheet on Newton's third law, the students in group A consider the first several questions that the worksheet poses. The tutorial begins by stating Newton's third law and admitting that in some cases it seems not to make sense (an admission that is well supported by research into student understanding of Newtonian mechanics (Boyle & Maloney, 1991; Hestenes, Wells, & Swackhamer, 1992; Maloney, 1984)). The worksheet asks students to consider a heavy truck ramming into a parked, unoccupied car: "According to common sense, which force (if either) is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck?" The instructional activity is described in detail in (Elby, 2001).

In the episode below, "Kendra" (K) (6) expresses a common concern about whether the third law applies to the situation described; "Alan" (A) and "Jasmin" (J) try to reconcile the third law with the common-

sense intuition that the force by the truck would be larger. "Sheryl" (S) is present but does not speak in this episode. Italics denote quotations from the tutorial worksheet.

A: According to common...
K: Yeah, I think I don't understand this.
A: *According to common sense, which force, if either is larger during the collision: the force exerted by the truck on the car, the force exerted by the car on the truck?* Oh...
K: I mean, the truck.
A: The truck, yeah.
A: OK, so...
J: *According to common sense, which force is larger in the collision?* Tuh...
A: What?
J: Why are they asking that?
A: Oh, OK, the car...
J: question...
A: *Is your group's explanation in Part A similar or different?* It's similar.
J: Intuitively, the car reacts more, you'd rather be riding in the truck, so the car feels... *is your group's explanation similar or different?*
A: It's the same. Right. OK, so, *according to Newton's Third Law, which of the... which of those forces...*
K: It says they're equal, right?
A: Yeah. Should be equal.
K: I kinda, I could never understand that, but.

K (cont.): Does this go against the law then, or is it that they are equal but we just think it's the truck? You understand what my question...
A: We think it's the truck because the truck doesn't move backwards, I think. Right? Cause if there's equal and opposite forces, the truck... we would, if we actually saw it, we'd think the truck would hit the car and go backwards because of the force, but since...
J: Maybe they do exert the same force, but the truck doesn't move.
A: The truck doesn't move cause I think it's got the momentum going, and... you know.
K: So they, they are doing the same force, it just doesn't... it's just not common sense.
A: Yeah, it just doesn't register because we see the truck (K: It looks as being bigger) still moving forward, right, right.

Behavioral coding

In the first part of the episode (until the horizontal line), students lean over their papers and only briefly glance up at their peers. They rarely gesture, and their faces and voices are relatively neutral. Their speech consists largely of phrases read from their worksheets. Overall, their behavior is well-characterized by the blue behavioral cluster. At the moment indicated by the horizontal line in the transcript, however, the students' behavior changes abruptly to that of the green behavioral cluster: They sit up and make eye contact with one another, make original statements in clear, loud voices, and gesture relatively prolifically. The green behavioral cluster continues to the end of the episode.

There are exceptions to the above characterization of student behavior in the episode. Right at the beginning of the episode, Kendra's statement, "Yeah, I think I don't understand this," is unusually clear, original speech compared to the other utterances that take place shortly before and after it; she is not reading from the worksheet, and her voice is relatively loud and animated. Other aspects of her behavior, though, remain consistent with the blue behavioral cluster – for example, she remains bent over her worksheet. Kendra's statement appearing immediately before the shift from blue to green, "I could never understand that," is similar in both content and tone to the slightly anomalous statement at the start of the episode. We interpret the momentary contrast between her behavior and the group's in the next section.

Substance of student thinking

The contrast between the blue and green behavioral clusters is reflected in the substance of students' speech. While students are exhibiting the "blue" behaviors, their speech consists mostly of reading worksheet questions aloud. They offer only brief answers to or comments about the questions, and they ask only two questions of their own: one to verify an answer ("It says they're equal, right?") and the other focused on the worksheet's intention ("Why are they asking that?").

The green mode begins with Kendra's question about the physics ideas: does this situation violate Newton's third law, or is there some misunderstanding? Alan responds with a perceptual reason why we might think the truck's force was larger (it "doesn't move backwards"), implicitly asserting that the forces are equal;

his explanation is incomplete, perhaps indicating that he's constructing it as he speaks. Jasmin adds to Alan's reasoning by suggesting that perhaps Newton's law holds in this situation ("they do exert the same force") but it's hard to tell because "the truck doesn't move" (by which she might mean that the truck's motion is relatively unaffected). Alan gesturally "waves off" the collision's lack of effect on the truck with reference to what he seems to identify as a different phenomenon ("momentum"). Kendra tries to affirm that the vehicles exert equal forces on one another in spite of common-sense convictions to the contrary. Alan agrees, and asserts that one may be misled by perceiving little change in the motion of the truck ("it just doesn't register because we see the truck still moving forward").

Epistemological framing

The changes in behavioral cluster from blue to green correspond with changes in the substance of the conversation. These two types of evidence together support our identification of the students' epistemological framing: They shift from framing their activity as *completing the worksheet* to framing it as *discussing the ideas*. This is a local shift; we expect these two frames are part of a larger framing of what is taking place in this tutorial session as a whole. Studying student behavior at this grain-size, we believe, provides insight into that larger framing as well as into its dynamics, including the coordination of the *worksheet* and *discussion* frames.

This identification of a shift in epistemological framing provides a basis for understanding Kendra's locally anomalous behavior. Kendra's initial statement may have been a *bid* for the group to change its activity; the group accepted her bid the second time she made it. We identify her bid for a frame change based entirely on her behaviors (*e.g.,* she is briefly more animated). The content of her speech, however, is also similar in the two cases: she denies understanding the situation. Her peers are likely to interpret such a statement as an implicit request for understanding. Such a request is more consistent with framing the activity as a discussion than with framing it as filling out a worksheet.

Summary and questions for future research

The behavioral clusters identified in the above analysis are evidence of students' epistemological framing. The behavioral cluster labeled "green," for example, which includes animated speech, eye contact, and gesturing, indicates a framing of the activity as discussing one another's conceptual ideas. Those behaviors do not only display that type of discussion – they also promote it. The association between framing and behavior advances the possibilities for identifying students' framing of collaborative active-learning activities. The methodology presented is powerful, reliable, and efficient, and adds substantially to previous analysis methods based on student speech acts.

Resource-based views of epistemological framing encourage theoretical continuity between individual and group (*i.e.,* cognitive and discourse) dynamics. A frame is a locally coherent pattern of activations that emerges from the interactions of many cognitive elements; these elements may be within an individual's mind or across multiple individuals, and the coherences may be within an individual's reasoning or among members of a group. Our approach illustrates an analyzable, codable dynamic between the way people behave in groups and the substance of their thinking. For example, a student who makes a kinesthetically evocative gesture may be at once using an intuitive sense of mechanism and, at the same time, communicating that the metamessage (Tannen, 1993) about what sort of conversation is taking place. Another student may move from blue to green behaviors, stimulating others to follow his lead (or not). To the extent that our account connects students' behavior, conceptual reasoning, and epistemological framing, it integrates individual cognition with group dynamics, and makes visible the interplay between conceptual reasoning and views of knowledge and learning at the level of both the individual and the group.

This analysis methodology makes a range of research questions empirically accessible. The examples above suggest many such questions: What frames occur in various classroom activities? In which frames do certain desirable activities (including cognitive activities) occur? What precipitates shifts into (or out of) desirable frames? Do particular learning activities have characteristic frames associated with them? Do student groups have characteristic framings of particular activities that they undertake together? Does a group's framing of particular activities change over the course of an hour, or a term? How might we best promote the substantive student discussion that we believe is essential to high-quality physics instruction? How can we account for the observed deterioration in student expectations and epistemologies?

These questions call for a variety of studies both within and across tutorial sessions. Within sessions, we are developing case studies of the particular dynamics by which a group moves into or out of framing the immediate activity as a discussion. These case studies may shed light on how students' framing of tutorials as a whole influences their moment-to-moment activity, and how patterns of behavioral clusters may vary for a particular group over the course of a term, or vary by tutorial.

Endnotes

(1) Frames, scripts, and schemata are related and overlapping terms in the fields of linguistics, artificial intelligence, cognitive psychology, social psychology, sociology, anthropology, and other disciplines. An overview and history of the uses of these related terms appears in Chapter 1 of Tannen (1993).

(2) Linguistic markers include omissions, repetitions, negatives, modals, *etc.* and are described in Ch. 1 of Tannen (1993).

(3) There is the possibility of the speaker acting as though she is engaged in a lively discussion while in fact not experiencing genuine engagement. For frame analysis in the context of acting, see Goffman (1986).

(4) This result is partially to be expected: since peers' activity together is mutually constructed, it is natural that they should share their framing of a given situation and therefore participate in the same behavioral cluster. On the other hand, it seems possible that individuals could "opt out" of the framing mutually constructed by the others in the group. This paper reports brief occurrences of such opting-out or mismatch of framings. However, the great majority of the time, peers share the same behavioral cluster.

(5) Sometimes, for example, they exhibit "green" behaviors with a TA nearby or even joining the discussion.

(6) Students' names are pseudonyms.

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