ABSTRACT

Title of Document: BUILDING SHARED UNDERSTANDINGS IN INTRODUCTORY PHYSICS TUTORIALS THROUGH RISK, REPAIR, CONFLICT & COMEDY

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Collaborative inquiry learning environments, such as *The Tutorials in Physics Sensemaking*, are designed to provide students with opportunities to partake in the authentic disciplinary practices of argumentation and sensemaking. Through these practices, groups of students in tutorial can build shared conceptual understandings of the mechanisms behind physical phenomena. In order to do so, they must also build a shared *epistemological* understanding of what they are doing together, such that their activity includes collaboratively making sense of mechanisms.

Previous work (Conlin, Gupta, Scherr, & Hammer, 2007; Scherr & Hammer, 2009) has demonstrated that tutorial students do not settle upon only one way of understanding their activity together, but instead build multiple shared ways of understanding, or *framing* (Scherr & Hammer, 2009; Tannen, 1993a), their activity. I build upon this work by substantiating a preliminary finding that one of these shared

ways of framing corresponds with increased evidence of the students' collaboratively making sense of physical mechanisms. What previous research has not yet addressed is *how* the students come to understand their activity as including collaborative sensemaking discussions in the first place, and how that understanding develops over the course of the semester. In this dissertation, I address both of these questions through an in-depth video analysis of three groups' discussions throughout the semester.

To build shared understandings through scientific argumentation and collaborative sensemaking, the students need to continually make repairs of each other's understanding, but this comes with the risk of affective damage that can shut down further sensemaking discussions. By analyzing the discourse of the three groups' discussions throughout the semester, I show how each group is able to manage this essential tension as they each build and maintain a safe space to sensemake together. I find that the three groups differ in how soon, how frequently, and how deeply they engage in collaborative scientific sensemaking. This variability can be explained, in part, through differences in how the groups use hedging, irony, and other discourse moves that epistemically distance the speakers from their claims. This work highlights the connection between students' epistemology and affect in face-to-face interaction.

BUILDING SHARED UNDERSTANDINGS IN INTRODUCTORY PHYSICS TUTORIALS THROUGH RISK, REPAIR, CONFLICT & COMEDY

By

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2012

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Dedication

To my wonderful parents, Dave and Molly Conlin.

You have always given me the space and support to follow my dreams, and you have always taught me by your example how to do so with a smile.

Acknowledgements

This work was carried out with the support of the National Science Foundation, grant #044-0113. I would like to thank the NSF for their support.

I would like to express my appreciation for the support I have received from many colleagues, friends, and family. I would especially like to thank the following:

The folks at the University of Maryland, College Park, including, but not limited to, the Physics Education Research Group as well as the department of Curriculum & Instruction. I would particularly like to express my gratitude to the members of my dissertation committee, David, Joe, Andy, Janet, and Todd. I would also like to thank Ayush Gupta and Rachel Scherr for their great collaboration, mentorship, and friendship, as well as Lama Jaber, Jessica Watkins, Brian Frank, and my fellow grad students including Tiffany, Jen, Colleen, Kweli, Brian D. and all the rest.

Also, thanks to Patrick, Seamus and Monica Conlin. You have always paved my way in life with examples of how to live life to the fullest. Also thanks to Laura, who I think might actually be my guardian angel. And finally, I have to thank Michael, J., Dennis, and Craig—a band of brothers that truly helped me understand what it means to be part of a whole that is greater than myself.

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Chapter 1: Introduction and Dissertation Overview

INTRODUCTION

In this dissertation, I examine how groups of introductory physics students come to understand the nature of their activity within a non-traditional curricular context: The Tutorials in Physics Sense-Making.[1] In this chapter, I introduce the central aims of this research by first describing the tutorial environment, highlighting some of the obstacles students face in coming to a shared sense of what they are doing. Then I discuss research that has begun to address how the students overcome these obstacles. I present a pair of contrasting examples of tutorial groups' approaches to a particular tutorial problem, in order to illustrate what it means for groups to share an understanding of their activity that includes collaboratively making sense of physics. I conclude the chapter by stating my central research questions, and by providing a chapter-by-chapter overview of my approach to addressing them.

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[1] The Tutorials in Physics Sense-Making were developed by researchers at the University of Maryland, College Park. Building upon other reformed curricula (McDermott & Shaffer, 2001; Thornton, 1987), the tutorials background mathematical problem solving in favor of supporting students' reasoning about conceptual and epistemological issues in physics.

“What are we supposed to do?”—Building shared understandings in tutorial

The tutorials constitute a reformed component of the traditional algebra-based introductory physics course. They take the place of the traditional recitation section, where students typically sit facing the blackboard as a teaching assistant (TA) works through homework problems and answers students’ questions. In tutorial, the students sit in groups of four each week for 50-minute guided inquiry into topics discussed in that week’s lectures. Each student has a copy of a tutorial worksheet, which is designed to guide them through the conceptual and epistemological issues related to the physics content. Two tutorial instructors circulate amongst the student groups in order to encourage and support the students’ discussions.

The tutorials provide a more open-ended learning environment than the students in introductory physics may be accustomed to. Many of the worksheet questions have more than one correct answer, while others call for students to reflect on their learning of physics in ways that do not even have a pre-determined “correct” answer. Furthermore, the tutorial instructors play a very different role than in recitation. Instead of lecturing or answering students’ questions, the TAs facilitate the students’ discussions and generally encourage the students to work out their own answers to the tutorial questions. By emphasizing students’ own conceptual and epistemological reasoning over simply getting to “the correct answer” via mathematical problem solving, the tutorials can go against the grain of introductory physics students’ expectations about what it means to learn and do physics (Redish, Saul, & Steinberg, 1998).

The fact that students' views on what it means to learn physics can conflict with the tutorial designers and/or instructors complicates the task of building a productive understanding of what they are supposed to do in tutorial. Furthermore, their views can conflict with those of their fellow tutorial students (for an illustrative example, see Lising & Elby, 2005). For example, some introductory physics students believe that learning physics involves receiving knowledge from an authority (instructor, text, etc.), while others believe that learning physics involves an active process of constructing ones' own understandings (Hammer, 1994; Redish et al., 1998). Expectations can also vary with respect to the structure of physics knowledge, e.g., as a collection of isolated facts or as a single coherent system (Hammer, 1994; Redish et al., 1998).

These differences in students' beliefs can have drastic consequences for how students engage with the tutorials. A student who sees physics as a set of unrelated facts may not seek to resolve inconsistencies when they arise, for example, which can create tension with other members of their tutorial group. Through analysis of video from tutorial, Lising and Elby (2005) have provided an example of two students' contrasting epistemological stances getting in the way of their learning physics together. While one student was looking for a common sense explanation of how light travels, another tried to make it more "physics-oriented" by stringing together key vocabulary terms. Through their contrasting approaches, these two students showed a lack of a shared understanding of the nature of their activity in the moment. This in turn prevented them from working together to build a shared understanding of how light works at that time.

The case described in (Lising & Elby, 2005) illustrates the problem students face in tutorial: in order to collaboratively make sense of the conceptual issues, the students need to build a shared epistemological understanding of what it is they are doing together. They need to build this shared understanding out of a diverse set of beliefs about what learning and doing physics entails. Are they ever able to do so? If so, how?

Research on tutorial students' understanding of their activity has demonstrated that they are able to build shared understandings of what they are doing together (Conlin et al., 2007; Conlin, Gupta, Scherr, & Hammer, 2008; Scherr & Hammer, 2009). Scherr and Hammer (2009) analyzed the behavior and discourse of student groups in tutorial, finding that group members implicitly coordinated their activity in ways that demonstrated a shared sense of what they were doing together. In fact, the groups all displayed *multiple* shared understandings of what they were doing together, such as *having a discussion* or *completing the worksheet*. All of the groups spent most of their time within these shared activities, switching between them as a group either spontaneously or through implicit "bids" rather than through explicit discussion.

This dissertation builds upon previous research into introductory physics students' shared understandings of what they are doing in tutorial. While this research has demonstrated that tutorial students are able to build shared understandings of what they are doing, several open questions remain: How do students' shared understandings align with the instructional goal of the tutorials, which aim to engage students in the practices of collaboratively making sense of physics? How do the students initially build these shared understandings of their activity, and how do these understandings evolve as the semester progresses? In Chapters 3, 4, and 5, respectively, I address these questions in turn.

In this chapter, I first illustrate what it means for students to share an understanding of their activity, focusing on understandings of their activity that include collaboratively making sense of physics. I do so by presenting a pair of contrasting examples that show how two tutorial groups approach the same problem in different ways. I conclude the chapter with an overview of the rest of the dissertation.

ONE PROBLEM, TWO APPROACHES

In this dissertation, I examine how groups of students in tutorial build shared understandings of what they are doing together. For example, they could understand their activity as an opportunity to figure out physics together. Such an understanding would be in alignment with the aims of the tutorial curriculum. Alternately, they could understand their activity as a place where they have to complete the worksheet, or to have TAs and/or more knowledgeable students explain "the correct answers." My interest in what influences groups to engage with the tutorials in ways that are more like "doing science" than "doing the lesson" (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000).

So far I have suggested that students' contrasting views and beliefs can present obstacles for students as they build shared understandings of how to learn physics within the tutorial context. These contrasting views include their differing conceptual and epistemological understandings. Students in introductory physics have many contrasting conceptual understandings in physics, e.g. how an object's mass affects its rate of falling. But they also have many contrasting epistemological understandings, such as *whether* and *how* to resolve disagreements over conceptual issues. But what do these tensions look like in practice? What does it look like when students share an understanding that they should be "doing physics," and what does it look like when they do not share such an understanding?

In what follows, I will address these questions by presenting a pair of contrasting examples of how tutorial groups approach the same conceptual problem in tutorial. One group, the Bluebirds,[2] approaches the problem by appealing to their intuitive sense of cause-and-effect, and by resolving disagreements when they arise. This is evidence that this group shares an understanding of their activity that includes collaboratively making sense of physical mechanisms, in alignment with the tutorial's goals. The other group (the Ospreys) approaches the problem by appealing to their lecture notes, and although they note when inconsistencies arise, they do not work to resolve them. This group is understanding their activity in the moment in ways that are out of alignment with the tutorial's aim. By comparing and contrasting these episodes, I will illustrate what it means for students to share an understanding that they should be collaboratively making sense of physics.

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[2] For the purposes of referring to the groups, I have assigned them theory-neutral names that will remain consistent throughout the dissertation.

The loop-the-loop problem

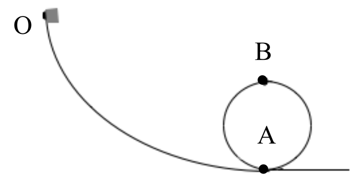

Figure 1.1—A cart is released at point O, goes down a hill, and goes around a vertical loop in the track. What forces act on the cart when it is at point B?

Both data examples come from the Tutorial 9, which deals with conceptual and epistemological issues related to the "loop-the-loop" problem (see Fig 1.3). This is a standard problem in introductory physics in which a cart is released at one point on the track (point O), rolls down a hill (through point A) and then around a vertical loop in the track. The ultimate goal is to calculate the minimum starting height at which a cart can be released and make it all the way around a vertical loop. As an intermediate step to solving the problem, the tutorial asks the students to draw all the forces acting on the cart at the top of the loop-the-loop (point B).

I have selected a segment from each groups' discussions in which they have been listing the forces acting on the cart at the top of the loop (point B). Both groups have included two forces acting on the cart: the force of gravity and the force from the track (a.k.a. the "normal force"). Both groups encounter disagreement over the direction of the force from the track is acting (up or down). The groups differ in how they approach this disagreement. Specifically, they differ in how they justify their ideas about the direction of the force of the track.

Example 1: The Bluebirds help each other make sense of the cart-track interaction

Figure 1.2—Amanda, Bree, Carmelle, and Deirdre are working on the loop-the-loop problem

The group I refer to as "the Bluebirds" consists of four students: Amanda, Bree, Carmelle, and Deirdre.[3] Through the coordination of their nonverbal behavior as well as the substance of their discussion, this group displays a shared sense of what they are doing together that includes collaboratively making sense physical phenomena. I will first describe their behaviors during this episode, before turning to the substance of their discourse.

The Bluebirds initially address the tutorial question in silence, by drawing diagrams of the forces on the worksheet. As they do so, the students are all hunched over their worksheets, their eyes are down, their hands on the table or writing. After about fifteen seconds, Bree looks up while the members continue their focus on their worksheets. At the end of that fifteen-second interval, the rest of the group suddenly shifts with Bree into a different cluster of behaviors. For the last fifteen seconds of the clip the Bluebirds are sitting up, making eye contact, gesturing, and building off

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[3] All student names are pseudonyms.

of each other's statements with animated voices. Following Scherr and Hammer (2009), we can say the group is transitioning from *completing the worksheet* to *having a discussion*.

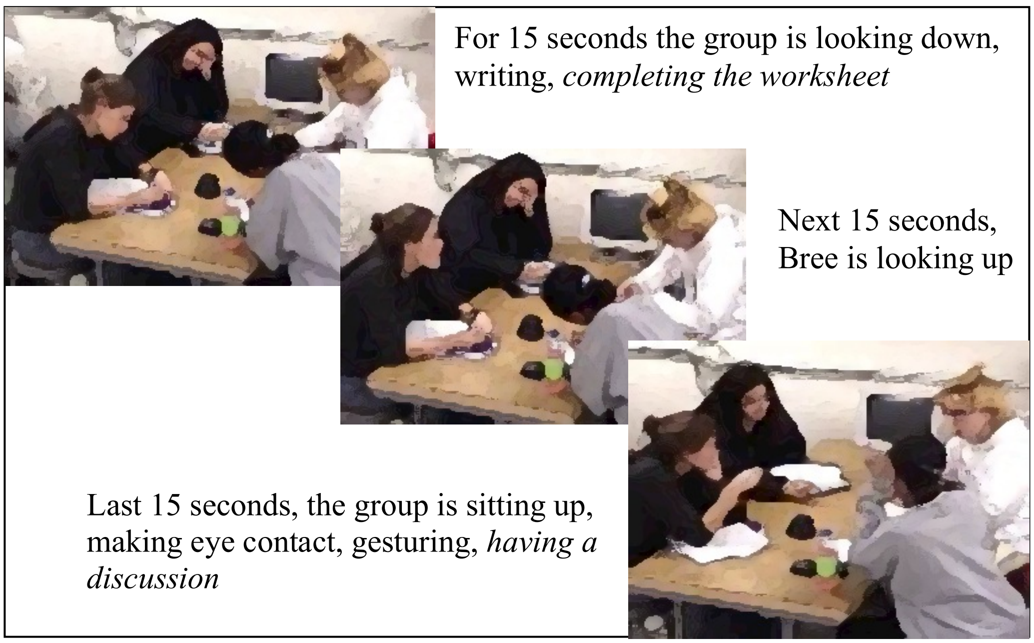

Figure 1.3—The group transitions from doing the worksheet to having a discussion

When Bree looks up it creates a contrast with the gaze of everyone else, which Bree can easily see as directed generally downward toward the worksheet. She breaks away from the common activity of quietly filling in the worksheet, and begins to orient to the group space. This gets taken up by the group as a bid to discuss things, as they quickly join Bree in orienting to the group space by sitting up, making eye contact, speaking, and accompanying that speech with gestures.

These claims about the student's behaviors are substantiated by the substance of what the students are saying during this time. While they are focused on their worksheets, the students are largely silent. After the transition, they share their ideas about what forces are acting on the cart at the top of the loop.

	(30 seconds of silence)
BREE:	Okay.
AMANDA:	Ohmygod.
BREE:	Alright...(5 second pause)...There's mmm...
DEIRDRE:	Well there's gravity
BREE:	Gravity's going down...

Bree breaks a long silence by saying, "Okay." This signals an orientation to the group space—or at least that's how it gets taken up by the others, who then start to break their silence as well. Amanda utters, "Ohmygod," which has the feel of a commiserating complaint, as if to say "This is tough," or "This is painful." The Bluebirds proceed to name the forces that they have in their free body diagrams. Bree opens up this process up with, "There's mmm…" This statement, taken out of context, is thoroughly vague. But Deirdre takes up Bree's formulation and adds to it, "Well there's gravity." Bree responds that "Gravity's going down…," which agrees with Deirdre's inclusion of gravity as a relevant force but also adds a direction to it. And so, the Bluebirds are establishing a shared understanding that gravity is going down.

Although I am interested in the shared conceptual understandings that the groups build, I focus on that only in the service of my central focus of how the students share an understanding of what they are doing. The means by which students groups build shared conceptual understandings is an important indicator of their shared epistemological understandings of the nature of that activity. In the present example, The Bluebirds are acting as if they share a sense of what they are doing; naming the forces on the force diagram. They did not explicitly agree upon having a discussion, nor did the tutorial tell them to discuss their force diagrams. Even without explicit instructions to do so, they are using their discussion to build a shared understanding of the physics of the interaction between the cart and the track.

Having established that gravity is down at the top of the loop, The Bluebirds proceed to discuss the next force to include, i.e. the force that the track exerts on the cart. While the Bluebirds all agree that the diagram should include this force, they disagree about its directionality:

CARMELLE:	I mean you have the force of the track pressing it down,
BREE:	The force of the track pushing down.
DEIRDRE:	But wouldn't it-
AMANDA:	Going down.
DEIRDRE:	Would it be going up or would it be going like, (drawing) like that?
BREE:	What?
DEIRDRE:	The force of the track.
BREE:	Nah, it's going down.
CARMELLE:	Cause its pressing down on it, it’s at- it’s at the top part it that top part of is is what's pushing down (gesture: one hand on top of other)
BREE:	(overlapping with Carmelle)...pushing down, cause that's what's holding it in from like being shot like way out (gesture: pointing away from body w/ index finger & shooting hand away)

In this strip of talk, Carmelle, Bree, and Amanda initially establish a mutual agreement that there is a force from the track, which is pressing down on the cart. Deirdre implicitly agrees that this force should be included, while disagreeing about its direction: “But wouldn’t it-…Would it be going up or would it be going like that (drawing)?” This prompts Carmelle and Bree to first establish that they are all talking about the same force before correcting Deirdre’s understanding of the direction.

In the process of making this correction, both Bree and Carmelle provide justification for the force's downward direction. Carmelle's argument for the track pushing downward is based on where the track and cart are positioned relative to each other. "It's at that top part of it. That top part is what's pushing down."

Figure 1.4—Carmelle explains why the normal force pushes down, based on where the cart is relative to the track

Although her words are a bit vague, Carmelle accompanies that statement with a gesture that makes her explanation clear. Using her left hand to represent the cart, and her right hand on top of it to represent the track, Carmelle shows that it is in virtue of the track being above the cart that it must be pushing down on it. Carmelle bases her justification on her sense of what is going on between the cart and the track, as opposed to say, basing it on the authority of what was said in lecture (as the next group will do).

Bree also reasons about the track-cart interaction in support of her answer of the normal force being directed downwards. In Bree's explanation, she highlights the competing inward and outward influences on the car, the interaction of which lead to the cart's resultant circular motion. She reasons that there must be a downward force from the track that is counteracting the cart's tendency to fly off, thereby constraining it to move in a circular path. The track is "pushing down," in Bree's words, "cause that's what's holding it in from like being shot like (gestures) way out." Bree uses her hands to represent the competing influences on the cart's motion by pointing in, then out:

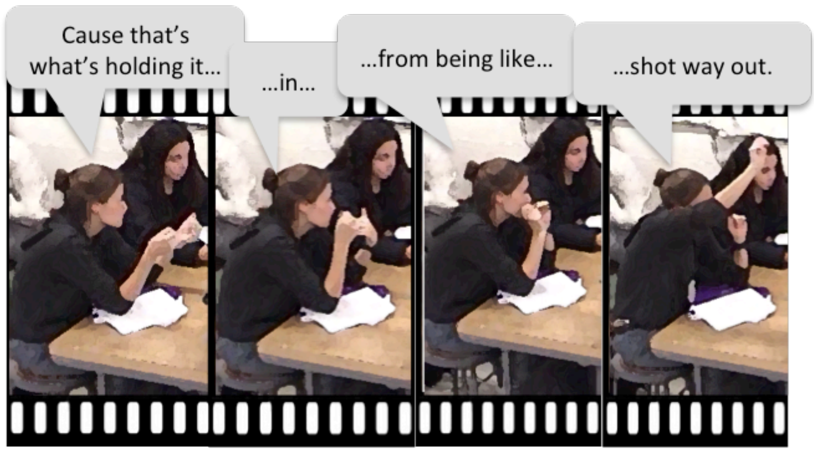

Figure 1.5—Bree explains why the force must be downward (inward), to counteract the cart's outward influences

Example 1 Summary & Discussion—The Bluebirds went from individually doing the worksheet to having a group discussion, a transition that began when Bree raises her head up and started list the forces acting on the cart. In their discussion about the forces acting on the cart at the top of the loop-the-loop, they all agreed on the presence of two forces, gravity and the force from the track, but they disagree on the directionality of the latter force. In convincing Deirdre of the downward direction of the normal force, the students appeal to their intuitive sense of the physical interactions between the cart and the track. After Carmelle and Bree each provide a mechanistic reason that the force would be down, Deirdre concedes the point without further discussion and the group moves on.

The way the Bluebirds handle their disagreement demonstrates a shared understanding of their activity that they should be making sense of physical mechanisms, in alignment with the goals of the tutorial. This is evident in both the fact that Carmelle and Bree each provide mechanistic reasoning to support their answer, and that Deirdre is convinced by this reasoning. In what follows, I will analyze a group that does not seem to be understanding their activity in this way.

Example 2: The Ospreys miss an opportunity to make sense

The Ospreys (Britte, Cena, and Devin) approach the loop-the-loop question in a way that starkly contrasts with the Bluebirds' approach. These differences are evident in the Ospreys' behaviors and discourse. I will briefly describe each in turn.

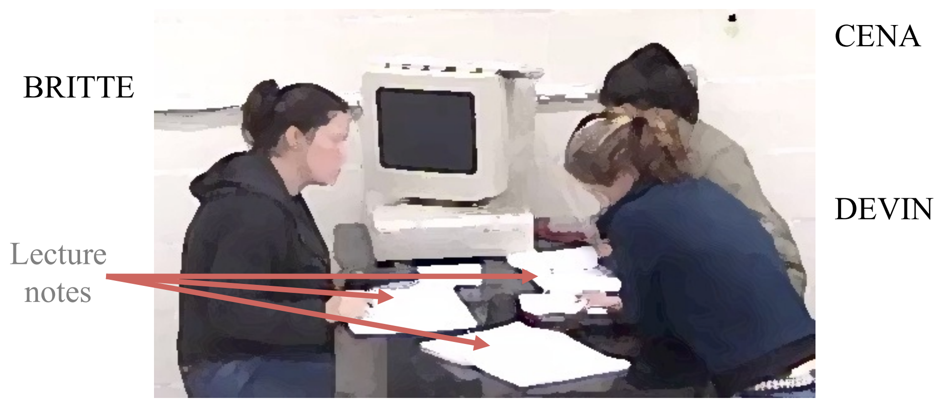

Figure 1.6—The Ospreys (Britte, Cena, & Devin) are working on the loop-the-loop problem

The Ospreys start out the question with their lecture notes out on the table, even though the TA had encouraged them earlier to put their notes away. Although this may be a small detail, it is reflective of the Ospreys' approach to this tutorial, i.e., translating each step of an example covered in lecture from their notes onto their tutorial worksheet. In contrast, the Bluebirds worked through the tutorial without ever referring to their lecture notes.

The Ospreys also display far less coordination in their nonverbal behaviors than the Bluebirds. While the Bluebirds transitioned together from completing the worksheet to having a discussion, the Ospreys generally remain hunched over their worksheets the entire time with only intermittent comments and questions. Analysis of the substance of these comments and questions reveals that the Ospreys are working to maintain consistency between their responses and their lecture notes, rather than making sense of the mechanism.

BRITTE: *(reads from lecture notes, looks up)*
We did this in class but, I don't think I wrote it down right.
(closes notebook and puts it down)
DEVIN: *(flips through lecture notes, starts writing on worksheet)*
BRITTE: *(glances back and forth between her worksheet and Devin's for about 1 minute)*
CENA: *(flips through lecture notes, then points at Britte's worksheet)*
Why does he say /times something/? I remember him writing that down, but why is it minus N.
BRITTE: *(opens lecture notes and reads, then points to Devin's worksheet)*
Are you sure that's just like N and MG? Because like, I have like written like N – MG and stuff like he talked about /??//
DEVIN: Right, that's for- *(reading silently for 30 seconds)*

The Ospreys are referring to their lecture notes to determine the forces on the cart at the top of the loop-the-loop. Like with the Bluebirds, they include the force of gravity (MG) and the force of the track (N). Also like the Bluebirds, there is some confusion over the direction of the force of the track on the cart, which Cena brings this when she asks Britte why the N has a minus sign. Instead of answering Cena's question directly Britte opens up her lecture notes once again, glancing at them before asking Devin about what she has written for the forces. This prompts Devin to look to her own lecture notes before formulating her answer. At this point they all consult their notes for thirty seconds before Britte once again breaks the silence:

BRITTE: *(reading from lecture notes)* "N minus MG equals force directed into the circle." ::: I guess if you're at point A, /isn't that the lower one/?
DEVIN: Yeah I have it written down MG – N = mv^2/r at the top.
BRITTE: At top, so that's /right/ at B
DEVIN: Yeah
BRITTE: /So that's/ when you're at B...You're here,
DEVIN: Yah.
BRITTE: *(pointing to DEVIN'S notes)* That equation.
DEVIN: Yeah.
BRITTE: Okay.

After consulting their lecture notes, it seems that the group agrees that the sum of the forces at the bottom of the track (point A) should be N – MG, while at the top (point B) they should be MG – N. A few moments later it becomes apparent that this agreement was unstable:

CENA: *(looks at Devin's then her own for 15 sec)* So, what- what do you guys think for the A then. Did you put MG – N?
BRITTE: Yyyeah. Cuz- *(looks at Devin's worksheet)* like why didn't you put MG – N...for the bottom.
DEVIN: *(looks at worksheet, then at lecture notes)*
BRITTE: *(pointing at Devin's worksheet)* Cuz at the top here, MG – N...will give you...
DEVIN: /Cuz/ it's asking us to draw the free body diagram, right?
BRITTE: Mmhm,
DEVIN: And these *(points to lecture notes)* that's what I have written down for the free body, is just the- *(points to notes, then turns page)*

The conversation continues in this manner for another several minutes, before a TA comes by to check in with the group. The Ospreys' force diagrams surprise the TA, who notices that not only have they drawn the normal force in the wrong direction at point A, but they have also drawn the force of gravity going up.

Their behavior and reasoning in this episode indicates that while the Ospreys may share an understanding of what they are doing, this understanding does not include collaboratively sensemaking about the physical mechanisms. Instead, they repeatedly refer to the authority of their lecture notes. This way of understanding their activity in tutorial is out of alignment with the goals of the curriculum, and has negative consequences on their ability to build a shared conceptual understanding of the direction of the forces acting on the cart at the top of the loop-the-loop.

The Bluebirds' and the Ospreys' contrasting understandings of their activity

By comparing and contrasting the Bluebirds' and the Ospreys' approaches to the loop-the-loop problem, I have demonstrated what it means for the groups to have different shared understandings of the nature of their activity in tutorial. The evidence for their shared sense of what they are doing together lies in their coordinated behavior and reasoning. The Bluebirds abruptly and implicitly transitioned as a group between two distinct activities, from *completing the worksheet* to *having a discussion* about the physical mechanism of the cart-track interaction (as in Scherr & Hammer, 2009). They resolved discrepancies in their conceptual understandings by appealing to their intuitive sense of what is going on between the cart and the track. In contrast, the Ospreys' focus was on coordinating what was written in their lecture notes with what they have written on their tutorial worksheets. There is little evidence in the Ospreys' discourse that they are attending to the physical mechanism of the cart-track interaction.

The groups' contrasting approaches had consequences for their ability to build shared understandings of the conceptual issues raised in the tutorial. In response to a disagreement about their answers to this question, the Bluebirds discussed what is going on between the force and the track. At least in this case, such an approach enabled them to build a shared understanding of the direction of the track's force on the cart at the top of the loop-the-loop. The Ospreys also disagreed over the direction of the normal force, but they attempt to settle it by referring to their lecture notes. Their approach left the Ospreys unable to resolve this disagreement. The difference between the Bluebirds' and the Ospreys' approach involves whether and how they go about resolving their conflicting conceptual understandings. This approaching and managing conflicts reveals an underlying epistemological understanding about how to go about learning and doing science together.

I have posed these contrasting examples in order to clarify what it means for the groups to have a shared understanding of what they are doing. This still leaves the question of *how* the groups establish such a shared understanding in the first place. Another question that remains is how these shared understandings develop over the course of the semester. Addressing these two questions is the central aim of this dissertation. In what follows, I will give an overview of the rest of the dissertation, describing briefly how each chapter addresses these questions.

DISSERTATION OVERVIEW

In this dissertation I examine how groups of students in introductory physics tutorial build a shared understanding of the nature of their activity together. By way of contrasting examples of two student groups' approach to the same tutorial question, I illustrated that at least some groups come to share an understanding that they should be collaboratively sensemaking about mechanisms. This allowed me to formulate the central questions of this dissertation:

1. How do tutorial students build shared understandings of what it is they are doing in tutorial? More specifically, how do they come to understand their activity to involve collaboratively making sense of phenomena, in alignment with the tutorial aims?
2. How does that shared understanding evolve over the whole semester? More specifically, what contributes to the stability of this shared understanding that they should be collaboratively making sense of physics?

In Chapters 3 and 4 I establish the theoretical and empirical foundation for these questions in terms of epistemological framing. Then in Chapters 4 and 5, I address each of these questions in Chapter 4 and 5, respectively, by analyses of the groups' interactions at various points throughout the semester. In what follows, I will provide a chapter-by-chapter overview of my approach.

Chapter 2—Managing the Affective and Epistemological Dynamics of Collaborative Sensemaking Discussions in Physics Tutorials

In Chapter 2 I review two bodies of research that suggest the tutorial students will need to simultaneously manage conceptual, epistemological, and affective conflicts in order to build shared understandings of their activity in tutorial. The first is research on scientific argumentation in science classrooms, which suggests that students need to manage multiple levels of conflicts in order to frame their activity in ways that are authentic to the scientific practices of scientific argumentation and sensemaking. I introduce the term collaborative scientific sensemaking to identify the particular shared understanding the tutorial curriculum is aiming for the students to arrive at. I then connect up findings from research on scientific argumentation in the classroom with research on how people build shared understandings in face-to-face interaction more generally, a field known as discourse analysis.

Both of these literatures reveal a central tension faced by the tutorial groups as they are building of shared understandings. On the one hand, the groups must repair each other's understandings if they are to arrive at a mutual understanding, whether conceptual or epistemological. On the other hand, these repairs bring about emotional responses that can pull the students away from a focus on sensemaking. Having established this tension, I then draw from literature from on discourse analysis to identify some of the resources by which students in tutorial manage it. These resources include the students' epistemically distancing themselves from their claims (Kirkham, West, & Street, 2011; Kärkkäinen, 2007), through hedges and other sorts of footing shifts (Goffman, 1979; Goodwin, 2007a).

Chapter 3—Tracking Shared Understandings Through the Students' Coordinated Behavior and Reasoning

This dissertation builds on previous research on how students understand the epistemological nature of their activity, i.e., how they *epistemologically frame* their activity (Elby & Hammer, 2010; Hutchison & Hammer, 2010; Redish, 2004; Scherr & Hammer, 2009). In Chapter 3 I briefly review this research, which has established that the tutorial groups routinely establish not one but multiple shared ways of epistemologically framing their activity in tutorial. By reviewing the methods of behavioral and discourse analysis of the tutorial groups described in (Scherr & Hammer, 2009), I show how these framings are easily recognizable by the group-level transitions in behavior. I then substantiate a preliminary finding reported previously (Conlin et al., 2007; Scherr & Hammer, 2009) that the discourse within one of these share framings is significantly more mechanistic than the discourse at other times. This finding means that by using a reliable method behavioral coding, I can select video clips of tutorial groups' interactions when they are more likely to be framing their activity as collaborative sensemaking about mechanisms. What this research does not address is how these shared framings get established in the first place, and how they evolve over the semester. I will address these open questions in Chapters 4 and 5, respectively, by using the students' behavioral indicators to track the dynamics of three tutorial groups at various points throughout the semester.

Chapter 4—Making Space to Sensemake

To address the question of how the group first establishes these shared framings, it is critical to focus on their initial interactions. In chapter 4 I present a micro-analysis of three tutorial groups' first discussion of the semester, groups I refer to as the Bluebirds, the Sparrows, and the Ospreys. I examine how each group gets into their first discussion, by relying on linguistic resources such as turn-taking and epistemic distancing. I find a wide variation in how seriously each group takes the activity, and show how the Bluebirds take the activity more seriously than the other groups, ironically, by making fun of the activity.

These first discussions contain provide clues about how the groups build a shared framing that they should be collaborative scientific sensemaking within each groups' discussions. I then provide a microanalysis of the first discussion that each group shows significant evidence of collaborative scientific sensemaking, examining what precipitated it and what stabilized it. In every case, I show that small things make a big difference, whether it is an instructor overhearing a good question, or a new group member wording her question in such a way that challenges the burgeoning norms of the group.

Chapter 5—Long-Term Dynamics of Groups' Collaborative Sensemaking

Having addressed the question of how the groups initially build a shared framing of their activity as collaboratively making sense of physical phenomena, in Chapter 5 I turn to the question of how this framing evolves over the semester. A qualitative analysis of the Bluebirds, the Sparrows, and the Ospreys over the entire semester reveals that the dynamics of the groups' framings of their activity are complex. Their understanding that they should be collaboratively sensemaking is challenged by a variety of mixed messages about what it is they should be doing they encounter as they progress through the early tutorials. I present a case study of one group's bumpy road towards sensemaking, in which they manage contrasting messages about whether they should be sensemaking about some unexpected "jumps" in their motion graphs. This case shows how mixed messages may inevitable in such a flexible learning environment, and some of these messages may end up having unintended consequences. This also highlights the importance for *distributed responsiveness* across multiple aspects of the curricular context, including the tutorial instructors and the worksheets. I show how in several instances the TAs depart from the written instructions in order to take up an opportunity to engage the students in sensemaking, and these departures prove critical for the groups understanding that they should be making sense of the physical mechanisms.

Having characterized the complex dynamics by which students' shared framings evolve over longer timescales, I then examine the groups' activity later in the semester. With brief examples from the data, I present a portrait of the groups in week nine of the semester. Building upon the data examples presented in the current chapter, in Chapter 5 I compare and contrast how all three groups frame their activity during their discussion of the forces on a cart at the top of the loop-the-loop. The Bluebirds and Sparrows each show signs that they understand their activity in this moment to include collaboratively making sense of the mechanism, while the Ospreys do not. I then relate this example to more general observations of each of the three groups at this point in the semester. I find that all three groups do build a shared understanding of their activity as collaborative sensemaking, although there is a wide degree of variability in how often and how stably they do so. I argue that these differences can in part be explained by how the groups manage the epistemological and affective dynamics of resolving conceptual conflicts, for example, through epistemically distancing them from their claims and stances.

Chapter 6—Conclusions, Implications, and Future Directions

In Chapter 6, I first summarize the findings of the research presented in this dissertation. In addressing how students build shared understandings of what they are doing in tutorial in ways that include collaborative scientific sensemaking, this work highlights the central role of the epistemological and affective dynamics of the group's interaction. As the students progress towards sharing an understanding that they should be sensemaking together, they must navigate ambiguities and repair understandings at multiple levels, while simultaneously manage the affective damage that can come from such repairs.

Another finding is that the student groups manage these dynamics with varying degrees of success. As the picture painted of these groups shows, this variability derives from the complex dynamics of the groups' paths towards building a shared framing of what the tutorial is about. I briefly illustrate this point by presenting an example in which one group, through a series of ambiguous statements, arrives at a shared understanding that they should have a sensemaking discussion. This case shows that ambiguity, although ubiquitous, is not simply an obstacle to building shared understanding; it is a matter of how the groups take it up. I have shown in this dissertation how if it is taken up in the right way, ambiguity with respect to whether a student means what she is saying can help fuel the whole process of constructing a safe space to sensemake.

Analysis of the group's management of these tensions reveals that the groups do not navigate this process alone, a finding from this research that has implications for instruction and curriculum design. I have shown examples of small moves of the TAs having a lasting positive impact on the students' framing of the tutorial as an opportunity to sensemake together. For instance, TA Joey overheard a good question, and used it as an opportunity to get the Sparrows sensemaking for the first time. Then he used the whole interaction as an opportunity to repair their understanding of what it is they should be doing in tutorial. I have argued that this sort of responsiveness is a crucial component of the distributed responsiveness of the tutorial curriculum, which includes a large degree of openness and flexibility in the tutorial worksheets. While coherence amongst the various components of the curriculum is should be an overall goal, I have shown how mixed messages inevitable arise and how their net effects on the students' progress can often be a positive one.

Finally, I conclude Chapter 6 by pointing to some of the open questions that remain, which could prove to be fruitful directions for future research. For instance, this dissertation focuses on the group more so than the individual students. Further research is needed to unpack the ways the shared understandings at the group level impact the learning of individual students.

Chapter 2: Managing the Affective and Epistemological Dynamics of Collaborative Sensemaking Discussions in Physics Tutorials

CHAPTER INTRODUCTION

On the first day of class, students in the introductory physics tutorials face a daunting task. They sit down at a table with three unfamiliar students, each with their own tutorial worksheet, and they need to quickly figure out what they are supposed to do together. This task is complicated by the fact that research on students in introductory physics courses suggests that they come in with a variety of contrasting conceptual understandings (Halloun & Hestenes, 1985; Thornton & Sokoloff, 1998) as well as different expectations about what learning physics is all about (Redish, Saul, & Steinberg, 1998; Lising & Elby, 2005). A subset of this research has highlighted students' multiple ways of understanding the epistemological nature of their activity, i.e., their *epistemological framing*, within introductory physics classrooms (Elby & Hammer, 2010; Redish, 2004; Scherr & Hammer, 2009). This research suggests that if students are to build a shared sense of what they are doing together in tutorial, they must work through a variety of conflicting ideas, expectations, and understandings.

To further complicate matters, they must organize their activity with far less explicit instruction from either the worksheets or the teaching assistants (TAs) than they may be accustomed to. The Tutorials in Physics Sensemaking are a reformed component of a traditional introductory physics course, replacing the weekly recitation sections with a 50-minute guided inquiry. The students collaborate in groups of four on a worksheet designed to address various conceptual and epistemological issues related to the lecture topics of that week. Both the TAs and the worksheets support the students in taking up discourse practices that are authentic to how science is done, such as making sense of physical phenomena, considering multiple perspectives, and resolving contrasting intuitions. In this way, the tutorials have affordances turning the students' conflicting ideas into opportunities for learning the content and process of physics. But amidst all of the conflict and ambiguity, are the students able to construct a shared sense that this is what they should be doing? If so, how?

By and large, the tutorial students are able to work out this problem, as suggested by previous work on students' interactions in tutorials (Conlin, Gupta, Scherr, & Hammer, 2007; Scherr, 2009; Scherr & Hammer, 2009). This research indicates that many student groups generally share a sense of what they are doing (i.e., a shared *framing* of their activity) for most of the time spent in tutorial (Scherr & Hammer, 2009). Moreover, the groups form *multiple* shared framings of what they are doing. Behaviorally, each group transitions back and forth between a small set of distinct behaviors. Analysis of the discourse within these behavioral clusters show that they correspond with different ways the groups are framing their activity, e.g., as *having a discussion,* or as *completing the worksheet*. Further evidence suggests that one of these shared framings involves a disproportionately high amount of evidence of the students reasoning together about mechanisms (Conlin et al., 2007; Scherr & Hammer, 2009), a claim I will further substantiate in Chapter 3.

While these studies have demonstrated *that* students in tutorial are able to build shared understandings of what they are doing, these studies do not specifically address *how* the students are able to arrive at these shared understandings. This forms one of the central aims of this dissertation: to develop an empirical account of how the tutorial students build shared understandings of their activity. Particularly, the focus is on how they come to frame their activity as collaboratively making sense of physics. Chapter 4 provides a close empirical analysis of the interactional processes by which students construct mutual understandings of what it is they are doing in tutorial. Chapter 5 contains an analysis of the stability of the students' framing over the course of the semester. The current chapter provides the foundation for these later chapters by providing the theoretical constructs and analytical tools for those analyses.

In this chapter, I review several areas of research to support the case that in order to build shared understandings through the authentic disciplinary practices of argumentation and sensemaking discussions, students must manage conflict of many sorts, including conceptual, epistemological, and affective tensions. In making this case, I situate this dissertation at the intersection of two main bodies of literature: research on scientific argumentation (Berland & Hammer, 2011; Driver, Newton, Osborne, & others, 2000; D. Kuhn, 1992; D. Kuhn & Udell, 2007) and research on how people building shared understandings in face-to-face discussions, a field often referred to as *discourse analysis* (G. Brown & Yule, 1983; Schiffrin, Tannen, & Hamilton, 2001; Van Dijk, 1985). I identify conflict resolution as a central issue within both literatures.

In Part I, I illustrate how conflict resolution is at the heart of both doing and learning science through the authentic disciplinary practices of scientific argumentation and sensemaking about physical mechanisms. Then in Part II, I demonstrate that conflict resolution undergirds peoples' ability to understand each other in face-to-face conversations more broadly. Drawing upon insights from discourse analysis, I then identify several of the resources students have at their disposal to manage multiple varieties of conflict simultaneously. In later chapters, I show these resources at work in students interactions in the tutorial classroom, as they contribute to (or take away from) their shared sense that they should be figuring out the physics together.

PART I—TO LEARN SCIENCE IS TO DO SCIENCE

Learning and Doing Science—Among other things, learning science means building shared understandings about both the body of scientific knowledge and the processes by which that body of knowledge has been forged. The students can accomplish both of these simultaneously when they are engaged in inquiry learning environments, such as the Tutorials in Physics Sensemaking, which are designed for epistemological authenticity. As argued in (Hutchison, 2008), to be an *epistemologically authentic* practice requires two things: (1) disciplinary authenticity, in which students are meant to engage in practices that reflect what scientists actually do, and (2) personal authenticity, in the sense that the learner finds the activities personally meaningful.[4]

The Tutorials in Physics Sensemaking are designed to provide students with opportunities to engage in various authentic disciplinary practices, including scientific argumentation and collaborative sensemaking. But whether something counts as an authentic scientific practice depends on one's view of the nature of science, and how it is practiced. I will address each in turn, first by defending a general characterization of science as the collaborative pursuit of coherent mechanisms, then by highlighting how this is accomplished in science, in part, via argumentation and collaborative sensemaking.

Science as the collaborative pursuit of coherent, mechanistic accounts of natural phenomena

Collaboration in Science and in the Science Classroom—The picture painted by modern philosophy of science highlights the fact that science is done increasingly through *collaboration* (Goldman, 2004; Thagard, 2006, 2007). Naturalistic studies of the collaborations of practicing scientists have incorporated a wide array of activities (Dunbar, 1993; Hara, Solomon, Kim, & Sonnenwald, 2003; Latour & Biezunski, 1994; Ochs, Gonzales, & Jacoby, 1996), from co-authoring a research report (Newman, 2004) to engaging in argumentation in the service of making sense of an

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[4] These are not really two separate things, a point recognized as early as Dewey (1910, 1998). Dewey recognized that unless the scientific pursuit is personally authentic to the students, it *cannot* be authentic to how scientists engage in science.

idea (e.g., Ochs et al., 1996) or some anomalous data (Brewer & Chinn, 1994; Darden, 2006).

Considering the growing importance of collaboration in science, epistemologically authentic curricula should give students opportunities to partake in scientific collaborations. But the fact that "doing science" can look so different makes the task of identifying scientific collaboration in the classroom a difficult one. There are many ways to collaborate, not all of which are equally "scientific." To address the question of what makes collaboration a scientific one, I review literature that identifies two core aims of scientific work, collaborative or otherwise: building mechanistic accounts of natural phenomena, and seeking coherence within and amongst those accounts. Identifying these aims within students' activities offers a sense of their scientific merit in a way that bridges the many varieties of scientific collaboration. Recent research in science education has emphasized this point, and has developed ways of identifying the mechanistic reasoning and coherence seeking within students' discussions. I will also review this literature in what follows.

Mechanism in Science and in Science Classrooms—Recent work in the philosophy of science has argued for the central role of causal mechanisms within accounts of nature put forward by science (Machamer, Darden, & Craver, 2000). Machamer et al. (2000) build upon a long history of accounts of scientific explanation in terms of mechanistic thought, dating back to Galileo's account of geometrico-mechanical explanations based on Archimedes' simple machines (p. 15). Mechanisms, according to this view, are regularities brought by entities and their interactions. A mechanistic account tells how the entities, their properties, and their organization lead to a reliable outcome. Given the right setup conditions, the entities and the interactions bring about terminating conditions with reliability. In other words, a mechanistic account of a phenomenon tells how the setup conditions leads to the terminating conditions via the intermediate activities of the entities. In their seminal work on mechanisms in science, Machamer, Darden and Craven (2000) presented the classic textbook account of chemical transmission at the synapse between two nerve endings, as just one illustrative example from a long tradition of mechanistic explanation in science.

Several researchers of science education have argued for the importance of identifying and encouraging students' thinking about causal mechanisms (Gopnik, Sobel, Schulz, & Glymour, 2001; Hammer, Russ, Scherr, & Mikeska, 2008; diSessa, 1993). Russ et al. (2008) make the case that mechanistic reasoning is a core element of scientific discourse, pointing out the need for instructors and researchers alike to attend to students' mechanistic reasoning in order to cultivate this aspect of students' thinking. They lay out a framework for identifying the mechanistic reasoning within student's ideas, which I will describe in more detail in Chapter 3.

Coherence Seeking in Science and in Science Classrooms— Research in philosophy of science (Thagard, 2007;1978) as well as science education (Olitsky & Loman, 2010; Redish & Hammer, 2009) has identified another central of science: to seek coherence within and amongst scientific explanations. Scientists seek coherence by making connections between explanations and resolving conflicts when they arise. Scientists work to resolve conflict through the coordination of theory and evidence, in the service of forming a shared holistic perspective of how the various mechanisms "hang together." They seek both *internal coherence* amongst the pieces of a single mechanistic account and *external coherence* across a wide array of interrelated mechanistic accounts of the natural world. The coherence seeking process can result in the rejection of a theory seen as incompatible with the evidence, or it could lead to the theoretical unification of compatible but previously distinct theories.

As (Schurz, 1999) has pointed out, there is a long history of prominent philosophers of science who have argued that the pursuit of coherence or unification lies at the heart of the scientific enterprise (Mach, 1883; Whewell, 1843; Feigl, 1970). One way in which coherence seeking is fundamental to science is reflected in the fact that it is generally presumed that scientific theories should be theoretically (and mathematically) continuous with each other. This is particularly true in physics, where the ultimate goal is the unification of our best theories of the known forces into a single "theory of everything" (Greene & Schwarz, 2000; Hawking, 2007; Weinberg, 1994).[5]

Researchers in science education have recognized the importance of students' seeking of coherence amongst ideas in the classroom, and have developed methods

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[5] Historically, this has proceeded via a stepwise unification of Maxwell's theory electromagnetism with the weak and strong nuclear forces into a single "grand unified theory" know as The Standard Model of particle physics (see, e.g., Weinberg, 1994). Modern attempts at unification aim to include the gravitational force as the final piece of the puzzle in a theory of everything (Hawking, 2007).

for identifying when students are seeking coherence. While early work has focused on assessing student ideas for coherence in written assessments (Shank & Ranney, Sandoval, 2003; Vosniadou & Brewer, 1992), more recent work has argued for the importance of attending to students' coherence-seeking behaviors in their science classroom interactions (Olitsky & Loman, 2010; Sikorski, Winters, & Hammer, 2009). Sikorski et al. (2009) used classroom video to identify two key varieties of coherence-seeking behaviors: when students are *seeking consistency amongst ideas*, or when they *are seeking meaningful connections amongst ideas*. According to this view, a student is seeking consistency amongst ideas when they orient to inconsistencies, such as a student who points out that clouds that are higher in the sky are colder, despite being closer to the Sun. A student is seeking meaningful connections amongst ideas when they piece together multiple ideas into a plausible mechanism, such as a student who explores plausible causal and temporal connections between clouds that are high in the sky, fog that is low to the ground, and puddles that are on the ground.

Seeking Coherence Through Sensemaking and Argumentation—One way that both scientists and science students can seek coherence amongst multiple competing ideas is through the practice of scientific argumentation. Argumentation in science includes a variety of coherence-seeking behaviors, including the consideration of multiple perspectives (Berland & Hammer, 2011, 2012; D. Kuhn & Udell, 2007), the coordination of theory and evidence (D. Kuhn, 1993), and sensemaking (Berland & Reiser, 2009; Roseberry, Warren, Conant, & Hudicourt-Barnes, 1992). Early work on scientific argumentation in the classroom catalogued various difficulties students encountered in coordinating theory and evidence through argumentation. For example, D. Kuhn (1991, 1993) assessed the argumentation skills of children, adolescents, and adults through their responses on written surveys and in clinical interviews, finding that people in all three age groups have general difficulties providing justifications for their claims based on evidence. More recently, Kuhn has studied children and adults' ability to coordinate children multiple perspectives in argumentation, finding again that both age groups have trouble, although young adolescents encounter more difficulties than adults (D. Kuhn & Udell, 2007).

These studies were largely conducted within laboratory contexts, "isolated from the verbal and social demands that argumentative discourse also entails" (D. Kuhn & Udell, 2007, p. 90). Such decontextualization raises concerns for the generalizability of these studies to classrooms. Perhaps as a result, more recently researchers' attention has turned to contextual factors, coinciding with a shift in focus to students' scientific argumentation in classroom settings. Berland and Hammer (2012) synthesizes research within this socio-cultural approach that supports a more favorable view of students' argumentation skills. Namely, the research has uncovered a great deal of students' nascent resources for argumentation, finding that students can do things that are more advanced than would be expected from earlier accounts. The difference is in the context, and on how the students are experiencing that context. This shift in focus towards the context dependence of students' skills of argumentation is evident in the more recent work of D. Kuhn (D. Kuhn, 2010; D. Kuhn & Udell, 2007). D. Kuhn and Udell (2007) found that while adolescents and adults each were able to provide justification for their claims when asked to do so, they tended not to provide justification in their own written arguments. The authors took this to indicate that while people do have nascent abilities for argumentation, they do not always see these abilities as relevant within the context.

But what makes for the right sorts of contexts for eliciting students' sophisticated argumentation skills? Berland and Hammer (2011, 2012) have recently synthesized a body of literature that suggests that the difference is in how the students' *framing* of their activity (Lakatos, 1980), i.e., their understanding of the nature of the activity that they take themselves to be engaged in. For instance, they contrasted three different framings of activity within a single classroom period. The overall task was for students to use a computer simulation of an ecosystem to identify the food source of an invasive species. At first, the classroom activity was focused on the generation and introduction of new ideas. In this activity the students were idea-sharing, a framing in which ideas were not challenged, only clarified. At other times, the classroom activity was framed as competition between multiple accounts of a phenomenon based, in which ideas were challenged based on theoretical considerations as well as empirical evidence.

A growing body of literature on physics students' *epistemological framing*, i.e., their understanding of the epistemological nature of their activity, has highlighted the multiple ways that students frame their activity in the classroom (Bing & Redish, 2009; Hutchison & Hammer, 2010; Redish, 2004; Scherr & Hammer, 2009). This work suggests that even when framing their activity as argumentation, students can have differences in framing that are critical for their participation in the activity and for their learning of science. For example, argumentation can be framed as a competition where only one idea can win (Berland & Hammer, 2011; 2012), or as an opportunity to help each other make sense of a mechanism (Scherr & Hammer, 2009).

These differences in framing have consequences for the affective and interpersonal dynamics of an argumentative discussion. Disagreements can cause frustration and embarrassment, and in some cases can devolve into shouting matches where the substance gets backgrounded or even abandoned completely (Barron, 2003; Berland & Hammer, 2012; Pondy, 1967; Tudge, 1989). The affective consequences of disagreement are not all negative, however. Disagreement can also act as a motivating factor that stabilizes students' engagement in scientific argumentation (Berland & Hammer, 2011).

Recent literature on argumentation and sensemaking in classrooms (Barron, 2003; Berland & Hammer, 2012; Engle & Conant, 2002) suggests that if groups are to collaborate in scientific argumentation, they must find a way to manage affective tensions, in addition to the conceptual and epistemological ones. My dissertation contributes to this research by revealing some of the processes by which the students manage these tensions in such a way that they can build a shared understanding of what they are doing that includes the authentic scientific practices of collaboratively figuring things out. In other words, they can epistemological frame their activity as including collaborative scientific sensemaking, a framing I will briefly characterize in what follows.

Collaborative Scientific Sensemaking In Classroom Discussions—Collaborative scientific sensemaking is a descriptive term for the processes by which science students (and scientists) build shared understandings about the natural world. It refers to the processes of a group of people working together to generate and critique ideas in the service of figuring out mechanisms at work in a natural phenomenon. In Chapter 3, I will be looking for evidence of times when students are framing their activity as collaboratively sensemaking in physics tutorials. In Chapter 4, I will analyze how the tutorial groups initially construct this shared practice, and in Chapter 5, I will examine what sorts of things stabilize or destabilize these practices throughout the semester.

This construct is presumed to incorporate many of the sophisticated practices of scientific argumentation, including the consideration of multiple perspectives and the seeking coherence amongst them. A precondition for scientific argumentation is that students' understanding of their activity is shared in at least two ways: (1) they must notice differences in opinions, and (2) they must seek to resolve these differences (Barron, 2003; Berland & Hammer, 2012; Engle & Conant, 2002). These are no simple feats, as the literature on students' difficulties with argumentation has highlighted (e.g., D. Kuhn, 1993). Both involve epistemologically sophisticated tasks such as considering multiple points of view (Driver, Newton, Osborne, & others, 2000; D. Kuhn, 1993; D. Kuhn & Udell, 2007), as well finding a balance between the processes of generating and critiquing ideas (Duschl, 2008; Duschl & Osborne, 2002; Ford, 2005).

The activity of collaborative scientific sensemaking necessarily involves the resolution of conflict, which comes along with a certain amount of risk to the socio-emotional dynamics of discussion. For instance, argumentation necessarily involves the threats to affect that come along with publically disagreeing with peers (Duschl, 2008). Damage to affect threatens to shut down the further production of ideas, and therefore shut down the scientific argumentation. I will characterize this tension more thoroughly in Part II, before addressing the question of how the students in tutorial go about resolving it.

Summary of Part I—So far, I have reviewed the literature on what it means to learn science by participating in authentic scientific practices, including research on scientific argumentation in the classroom. This literature highlights how the students are *framing* their activity (Berland & Hammer, 2011, 2012; Berland & Reiser, 2009; Scherr & Hammer, 2009), and also draws attention to the influence of affect and interpersonal dynamics on how students are framing their activity.

From this literature, I distilled a commonly talked about (but rarely defined) authentic scientific practice: *collaborative scientific sensemaking*. This practice is really a complex constellation of related practices, which I summarize as: *the process of generating and critiquing ideas in the service of building coherent mechanistic accounts of natural phenomena*. This process involves a complex dynamic with conceptual, epistemological, affective, and social dynamics. One essential tension this creates is that people have to disagree with each other, but disagreeing with each other can disrupt people's sustained engagement with the substance of the discussion.

In Part II I will put this claim on firm theoretical and empirical ground showing how it has arisen from the literature on discourse analysis, which suggests that conflict resolution in science is an extension of more general issues of conflict resolution that arise whenever people are building shared understandings.

PART II—WHAT DISCOURSE ANALYSIS TELLS US ABOUT BUILDING SHARED UNDERSTANDINGS THROUGH DISCUSSION

The big picture in both Parts I and II is the following: As long as a group can engage in conflict resolution while managing the socio-emotional consequences of that conflict, they can create a safe space to introduce and evaluate new ideas in the service of collaboratively make sense of a phenomenon. Conflict can thereby provide a tension that drives the progress towards shared understanding. This is analogous to the essential tension in science between convergent and divergent thought, which T. S. Kuhn (1977) argued is driving the whole process of science.

The same essential tension encountered in collaborative scientific sensemaking and argumentation also lies at the heart of building any shared understanding. The tension is this: *In order to understand each other we need to make repairs of understanding; meanwhile those repairs come along with the risk of damaging affect in such a way that can shut down the very discussion by which we try to build shared understandings*. No matter whether the understanding is conceptual (i.e., the direction of the normal force) or epistemological (i.e., "we should agree on the direction of the normal force"), the same processes of repairing ambiguity and discord are present.

In what follows, I will make this case by reviewing a few strands of literature within a body of research known as *discourse analysis* (Schiffrin, Tannen, & Hamilton, 2001), an interdisciplinary study of people in communicative interactions. I will review what discourse analysis says about the processes by which groups of people in interaction construct shared meanings, highlighting the ways they manage these essential tensions.

Managing conflict undergirds our ability to build shared understandings

Discourse analysis teaches us that our ability to understand each other is not to be taken for granted. We have to constantly work to build and maintain shared understandings, due in part to the fact that speech is inherently ambiguous.[6] To cut through the ambiguities of speech, participants in conversation must continually make repairs of understanding (Hirst, McRoy, Heeman, Edmonds, & Horton, 1994; Schegloff, 1991, 1992). But these repairs of understanding are manifestations of conflict, and as such they often come along with socio-emotional repercussions, such as the slight twinge of embarrassment that results from being corrected by a peer (Brown & Levinson, 1987; Goffman, 1955, 1956). In order to remain stably engaged in collaborative scientific sensemaking, then, students in tutorial must manage multiple dynamics of conflict, including repairs of understanding and of affect.

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[6] A variety of studies have shown that speech is inherently ambiguous at multiple levels. Syllables are underdetermined by the sounds we make (McGurk & MacDonald, 1976), words are underdetermined by syllables (Goldstein, 1983), meanings are underdetermined by words (Pinker, Nowak & Lee, 2008), and so on.

Making Repairs of Understanding—In order to come to shared understandings, we must make repairs whenever problems in understanding arise (Hirst et al., 1994; Schegloff, 1991). Discourse analysts have revealed that the implicit structures embedded in our conversations, such as the fact that we generally take turns, have built-in affordances for repairing understanding (Levelt, 1983; Schegloff, Jefferson, & Sacks, 1977; Schegloff, 1992, 1997).

Repairs of understanding can take place at many levels, from problems in hearing ("What did you say?") to problems in interpreting meaning ("I heard what you said, but what did you *mean*?"). Repairs can also be made to shared conceptual and epistemological understandings. For instance, Roschelle (1992) analyzed student discourse to identify the repairs they make to their converging conceptual understanding of acceleration vectors. In Chapter 5, I analyze in detail a clear example of a repair of the students' epistemological understanding.

Repairs manifest in variety of ways. Roschelle (1992), for instance, recognized repairs via their placement of within the sequence of the activity and converging meaning. Repairs can also be more explicitly signaled with a variety of discourse markers, ranging from something so small as a whispered "oh" (Fox & Schrock, 1999; Schegloff, 1997; Schiffrin, 1999), to something as dramatic as a shouted "No!!!!", a difference that can have dramatic social and affective consequences. An example from my data will help to illustrate how I analyze discourse to recognize students' repairs of understanding at various levels.

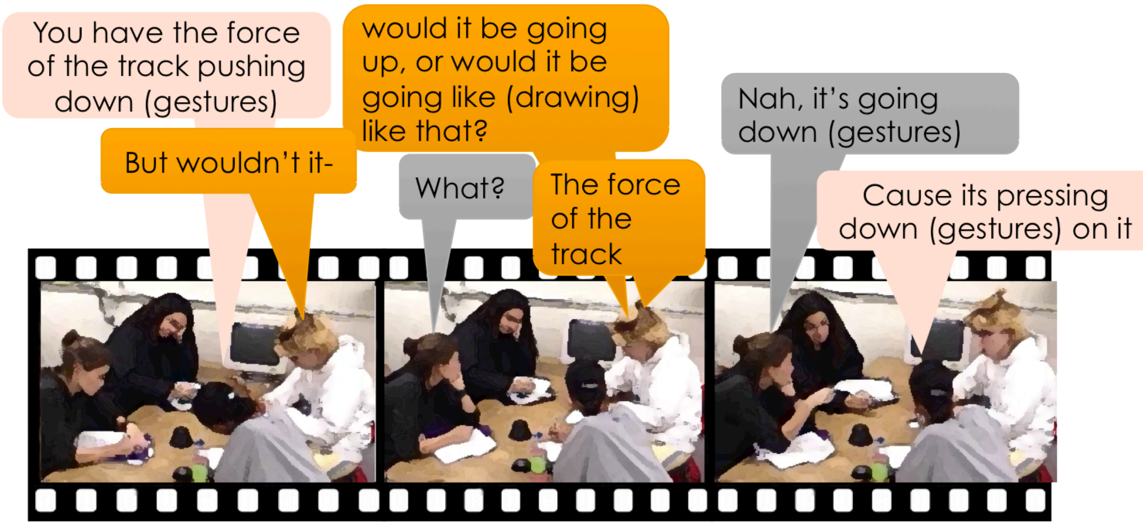

Figure 2.1—Repairs of understanding. The group accomplishes a repair of understanding with regards to which way a force is pointing, in response to Deirdre's question (white sweatshirt)

An excerpt from the clip discussed in Chapter 1 provides an illustrative example of the ways that students manage repairs to arrive at a shared understanding. In this clip, the tutorial group is listing all the forces acting on a cart as it goes around a circular track. Carmelle (grey sweatshirt) suggests they include the force exerted by the track on the cart, and describes the direction as downward. Deirdre (white sweatshirt) initiates a repair of understanding of the directionality of this force, asking if it might go up or even out in another direction (which she draws). Bree solicits repair of an ambiguity in Deirdre's speech with regards to which force they are talking about. Once Deirdre clarifies that she means the force of the track, Carmelle and Bree (black shirt) correct Deirdre by re-iterating that it is directed downward:

In this brief clip, the students are repairing their understandings at multiple layers. One layer is the repair of the group's shared understanding of the direction of the force of the track. As a result of this repair, the students end up "on the same page" with respect to the direction of the force of the track. But in the service of making that repair, Bree and Deirdre make a repair at the layer of ambiguities in the language. This repairs their understanding of which force they are even talking about.

Depending on its relation to the rest of the group's further interactions, this whole interchange could serve as a repair on their understanding of what it is they are doing together.[7] For instance, they could come out of this interaction with a more stabilized framing of the tutorials as being about making sense of physics. Alternately, it could shut down further sensemaking, say, if after being "corrected" Deirdre no longer feels comfortable sharing her ideas to the rest of the group. The difference in outcomes hinges on how the group manages the affective tensions resulting from the repairs of understanding, a case I will substantiate in the next section.

Maintaining Face, Even In the Face of Conflict—The act of being corrected carries with it affective risk. This risk can be weighed in terms of the loss of face that comes along with having one's understanding repaired. As Goffman (1955) described, we derive positive social value (i.e., "face") in virtue of pursuing a consistent line of reasoning throughout a conversation. Corrections to and deviations from this line thereby become threats to face, which result in the feeling of embarrassment (Goffman, 1955, 1956; see also Brown & Levinson, 1987).

Affective damage such as embarrassment can in turn threaten to shut down a conversation or discussion. In the case of students in physics tutorials, this plays out

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[7] In Chapter 5 I analyze in detail a clear example of such a repair.

when students become reluctant to share their ideas further, thereby short-circuiting the collaborative sensemaking process. In order to engage in collaborative sensemaking, students must find ways to manage the dynamics of making repairs to understanding while also managing the affective and social dynamics. In my dissertation, I aim to study how students and groups manage these dynamics.

The findings from discourse analysis show what the tutorial students are up against—they need to find a way to engage with conflicts (conceptual or epistemological) while also managing affect in a way that they can stably engage in collaborative sensemaking. The process of finding this balance is what I refer to in Chapter 4 as "making a safe space to sensemake." In the next section, I address the question of how students manage the conceptual, epistemological, and affective conflicts in order to build a shared understanding of what they are doing together. Drawing from research on discourse analysis on stance-taking and footing shifts, I then point out some of the nascent resources that students have to manage both sides of the tension, often at the same time.

How do students manage the conceptual, epistemological, and the affective dynamics of collaborative scientific sensemaking discussions?

In this section, I describe the basic processes by which people in conversation build shared understandings amidst ambiguity and discord, focusing on a set of linguistic resources that discourse analysts have referred to as *epistemic stance* and *shifts in footing*. This will enable me to formulate a class of linguistic resources by which students can navigate the conceptual, epistemological, and affect dynamics of conflict resolution in collaborative scientific sensemaking discussions in physics tutorials.

Taking Stances Through Shifts in Footing—To engage in authentic practices of scientific sensemaking and argumentation, the tutorial students need to take up opposing positions and stances. Research on discourse analysis has explored the dynamics by which speakers manage to take a stance within a conversation (Biber, 2006; Biber & Finegan, 1989; Clift, 2006; Goodwin, 2007a; Kirkham et al., 2011; Kärkkäinen, 2003). This research has revealed the interactional, dynamic, and multi-faceted nature of stance-taking. For instance, discourse analysts have examined how speakers take a stance by indexing their *epistemic* positioning with regards to their statement as well as their *affective* attitudes towards it (Clift, 2006; Englebretson, 2007; Goodwin, 2007a). Researchers have used the terms *evidentiality* and *epistemic stance* to refer to a speaker's positioning with respect to epistemological elements of their utterance, including the source of knowledge and their commitment to its truth (Chafe & Nichols, 1986; Kirkham et al., 2011; Ochs, 1996). Speakers can index their stance with respect to what they are saying through the use of discourse markers designed to serve this task, e.g., by prefacing their claim with a word such as "Presumably…" (Clift, 2006). Participants in a conversation can even index their stance through the positioning of they body (Goodwin, 2007a), for instance by orienting towards a particular sort of epistemological activity by huddling around a space of joint attention.

Research on stance-taking in conversation has also revealed that taking a stance is not black and white—there are many shades of grey. Speakers can upgrade or downgrade their epistemic stance through various discourse moves, for instance by *deferring* (e.g., "research has proven…") or by *hedging* (e.g., "I guess…") (Clift, 2006; Kärkkäinen, 2003, 2007). All of these linguistic resources for stance-taking can be accomplished in a variety of ways, from the explicit use of words ("I think") to the more implicit use of paralinguistic channels such as through a fall-rise intonation (Ward & Hirschberg, 1985).

One way that students in tutorial can perform an upgrading or a downgrading of their stance is by managing their *footing* (Clift, 2006; Kärkkäinen, 2003, 2007) with respect to their claims and stances. While *stance* refers to one's epistemic or attitudinal positioning with respect to the "truth" of a statement, *footing* refers to one's positioning with respect to who is behind its content, and to whom it is being addressed. Goffman (1979) identified three primary degrees of participation (i.e. footings) with regards to an utterance: *principal*, *author*, and *animator*. The principal is the person whose idea or stance is being expressed, the author is the one who is composing the message, and the animator is the one delivering the message. Typically, these are all one in the same person. In quoted in reported speech, however, a speaker can shift their footing in such a way that they are no longer necessarily the principal. If a child tells her brother, "Mom says you have to come inside," the child is the animator but Mom is the principal.

Footing shifts can be signaled through the substance of the speaker's utterance as in this case, but they can also be signaled in conversation via paralinguistic channels, such as shifts in register and prosody, facial expressions, body positioning, and gestures (Goodwin, 2007b; Hoyle, 1998). These channels are crucial for identifying footing shifts that are designed to be subtle, such as the case of irony, sarcasm, politeness, and other forms of indirect speech (Goodwin, 2007a; Hoyle, 1998). For instance, Clift (Goodwin, 2007a; Hoyle, 1998) has characterized conversational irony in terms of footing shifts that are often (but not always) signaled by linguistic and paralinguistic channels (e.g., laughter, smiling, nasal vocal register, sing-song, etc.).

Footing shifts have affordances for managing conflict. Research on discourse analysis has started to unveil how speakers use shifts of footing as resources for conflict management in written and in face-to-face conversations (Bonito & Sanders, 2002; Heisterkamp, 2006; Jacobs, 2002; Sharma, 2011). Bonito and Sanders (2002) demonstrated how students in collaborative writing tasks were able to use shifts in footing to wage or attenuate conflict while still engaging in attempts to resolve the disagreement. Heisterkamp (2006) used video analysis to examine how court-sanctioned mediators used shifts of footing to maintain neutrality in a small claims court.

My dissertation contributes to this work by examining one of the mechanism by which students manage conflict—by using shifts of footing to epistemically downgrade contrasting stances, a discourse move I call *epistemic distancing*. This allows opposing views to be expressed while protecting against the affective damage of disagreement. In Chapters 4 and 5, I report how students in tutorial often shift their footing in ways that soften their epistemic stance. For example, in reading her response to the first tutorial question, Bree shifts her footing by "reading what she wrote" in an ironic, performative manner, with exaggerated pitch variations, gestures, and facial expressions (see Fig 2.2).

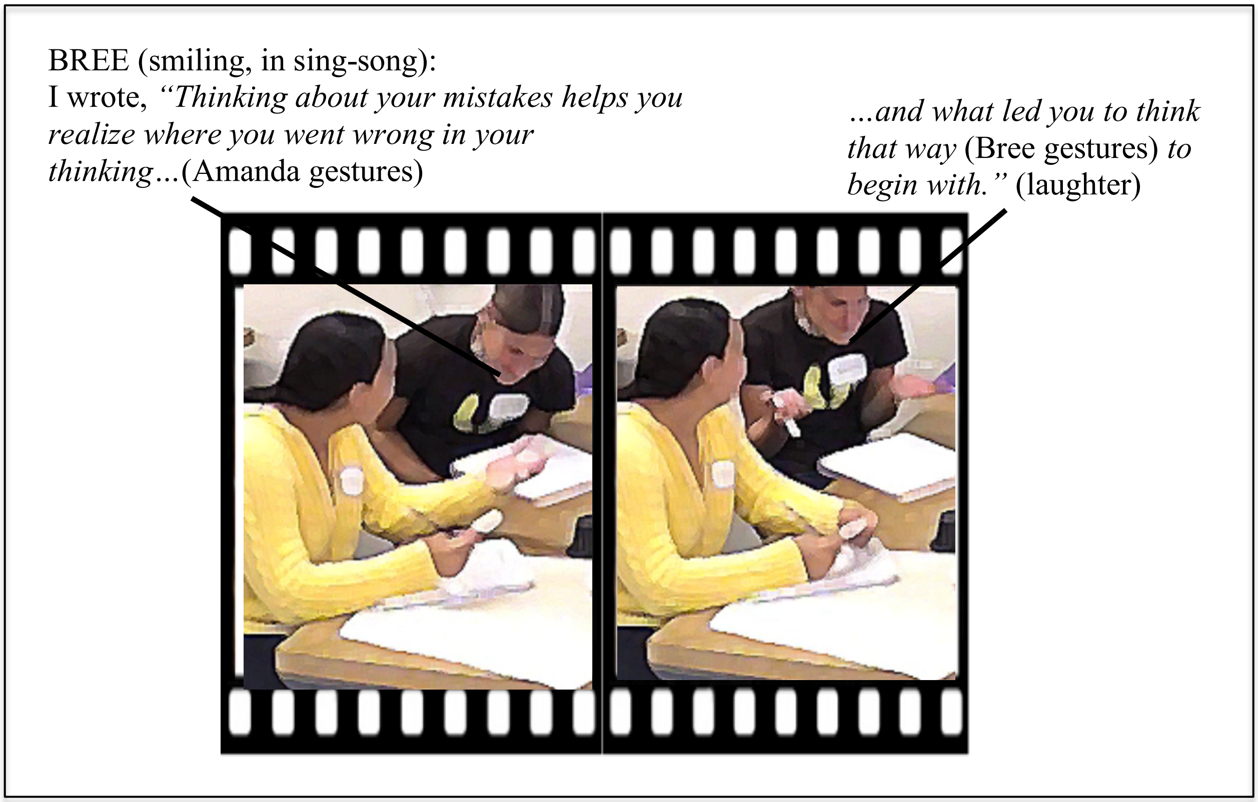

Figure 2.2—Bree reads her response to the first tutorial question. She softens the stance implied in her written words via an ironic shift in footing (Clift, 2006).

Bree's ironic shift of footing has the effect of epistemically downgrading the stance taken in her written response, by signaling that she does not take her response too seriously. By signaling an ironic shift of footing, Bree is epistemically distancing herself from the stance she takes and what she says. Instead of taking stance of, say, this is how it is, Bree could be conveying to the rest of the group a stance more like this is a position one might consider. In the words of Goffman, (1974, p. 512):

> When a speaker employs conventional brackets to warn us that what he is saying is meant to be taken in jest, or as mere repeating of words by someone else, then it is clear that he means to stand in a relation of reduced personal responsibility for what he is saying. He splits himself off from the content of the words by expressing that their speaker is not he himself or not he himself in a serious way.

Epistemic distance is a resource by which students can manage the epistemological and affective dynamics of conflict resolution simultaneously. Epistemologically, through shifts in footing, students routinely attend to multiple perspectives as they position themselves with respect to contrasting claims.[8] By softening their stance speakers can access more nuanced and sophisticated array of epistemic stances that are epistemologically authentic to how science is done, such as pursuing an idea without believing in it (Laudan, 1981; Whitt, 1990). The softening of stance also has affective consequences, for instance, by reducing the threat to face brought on by a repair or a rejection of their idea. In chapters 4 and 5, I argue how by simultaneously management of epistemological and affective dynamics of conflict resolution, the students in tutorial are able to build and maintain a shared

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[8] Findings such as this dovetail nicely with a rich literature that shows students have nascent resources for partaking in authentic scientific discourse practices, including the practices of considering multiple perspectives within the context of scientific sensemaking and argumentation (Berland & Hammer, 2011; Berland & Reiser, 2009; D Kuhn, 1993; D. Kuhn & Udell, 2007).

understanding of their activity that includes collaboratively making sense of physics. In brief, my argument is that by managing epistemic distance, students in tutorial can open up space for sensemaking discussions, or alternately they can shut down these discussions.

Opening Up And Shutting Down Sensemaking Discussions—Complementing the research on shifts of footing to manage conflict (Bonito & Sanders, 2002; Heisterkamp, 2006), several discourse analysts have addressed the consequences of *stance-taking* on affective and interpersonal dynamics (see Kärkkäinen, 2006, for a review). Several authors have specifically considered the effect of speakers' modification of epistemic stance on the affective dynamics of conversation, either through saving face or by causing loss-of-face (Brown & Levinson, 1987; Holmes, 1984, 1990; Nikula, 1996). By *hedging* with the phrase "I think," speakers can downgrade their epistemic stance in ways that avoid threats to the face of other participants in the conversation (Kärkkäinen, 2006).

Discourse analysts who have studied stance-taking in discourse have generally remarked on *the ability of hedging to simultaneously serve epistemic, affective, and social dynamics*, for better or worse (Clift, 2006; Johnstone, 2009; Kärkkäinen, 2006). My dissertation contributes to this research by providing details on these mechanisms through close attention to the microdynamics of epistemology and affect of student groups as they build a safe space to collaboratively sensemake together about physics. In Chapter 4, I expand upon the episode mentioned above in which Bree introduces epistemic distance through her ironic shift of footing. I argue that through these sorts of moves, Bree's group is able to ease away from "reading what they wrote" and towards "saying what they think." Situating this within the sequence of activity at the start of the tutorial, I show how this forms an important stepping-stone on the group's path toward establishing a shared understanding of the tutorial activity that includes collaborative scientific sensemaking.

CHAPTER DISCUSSION AND CONCLUSION

In this chapter, I have situated my research within a broader field that studies how people learning science through taking part in authentic disciplinary practices, particularly scientific argumentation and sensemaking. In part I, I have characterized an essential tension underlying the research described in this dissertation. On the one hand, science necessarily involves conflict in order to make progress, as manifested in the core scientific practices of coherence seeking and unification. On the other hand, conflict can break down the functionality of a scientific collaboration in the lab or in the science classroom. I have identified the particular sort of scientific collaboration I am interested in—collaborative sensemaking discussions. Ultimately, my dissertation is concerned with how student groups in physics tutorials are able to build a shared understanding that their activity should include collaboratively sensemaking about physics.

In Part II I showed how this tension manifests itself even in the most basic processes by which we build shared understandings. Conflict appears in the form of repairs of understanding, which are necessary for coming to some mutual understanding. At the same time, these repairs carry the risk of affective damage, which can shut down a tutorial group's ability to collaboratively sensemake about the physics. I explicated the connection between epistemic stance-taking and affective management through discourse moves such as hedging. I introduced one resource—epistemic distancing—by which students can introduce distance between themselves and the claims they are expressing. This softens epistemic stance in such a way that leave room for throwing out and critiquing ideas that is at the core of scientific sensemaking.

Looking ahead—This chapter sets the theoretical boundaries of my work and establishes some of the analytical tools by which I will accomplish it. Once again, the core question is how students in tutorial build and maintain shared understandings of the nature of their activity that includes collaborative sensemaking. Before establishing *how* they build these shared understandings, I will report on some of my previous research that helps establish *that* the groups do build these shared understandings in the first place. I will show that the tutorial groups tend to settle on a handful of shared behaviors that reflect shared framings of their activity. I will show that one of these framings exhibits more evidence for the groups' understanding as including collaborative sensemaking. Thus, in Chapter 3 I establish the criterion for identifying clips throughout the semester that are more likely to contain evidence of collaborative sensemaking. In later chapters, I use these clips to piece together the dynamics of how the groups form these shared understandings, as well as how they maintain them over the course of a semester.

Chapter 3: Tracking Shared Understandings Through Tutorial Students' Coordinated Behavior and Reasoning

INTRODUCTION

In the last chapter, I reviewed literature informing the question of how groups of people work to build shared understandings. I am interested in one particular type of shared understanding, namely, the understanding of what it is that the group is doing. Previous work has indicated that some of the ways a tutorial group frames their activity are more in line with the curricular goals than others. In the case of the Tutorials in Physics Sensemaking, the goal is to have the students collaboratively sensemaking about physical and epistemological phenomena in physics. In this chapter I present evidence that the tutorial groups are able to form several distinct ways of epistemologically framing their activity. Moreover, I will present evidence that one of these framings involves a significantly higher amount of collaborative sensemaking than the others.

In the first part of this chapter, I will build upon work that has been reported elsewhere (Conlin, Gupta, Scherr, & Hammer, 2007; Scherr & Hammer, 2009). Scherr and Hammer (2009) analyze the behavior and discourse of student groups in introductory physics tutorials. They found that the groups coordinated their behaviors, switching back and forth between several distinct behavioral clusters. By analyzing the discourse during these behavioral clusters, Scherr and Hammer found that they corresponded with different ways of *framing* their activity, i.e., different ways of understanding what sort of activity the groups take them themselves to be engaged in (Bateson, 1972; Goffman, 1974; Tannen, 1993a, 1993b).

To address my further focus on what sorts of shared understandings about the nature of the tutorial create space for collaborative scientific sensemaking, I will focus on the nature of the discourse during the "green" behavioral mode, when the students are framing their activity as *having a discussion*. I will present evidence the substance of the discourse changes during the discussion frame. In particular, the talk becomes more mechanistic, an important component of sensemaking in physics. Before we begin with the data analysis, however, I need to tell you what I mean by frames and framing.

ON THE NATURE OF FRAMES AND FRAMING

The construct of *framing* was first proposed by Bateson (1972) in order to explain how monkeys were able to remain in a sustained state of play fighting. Such activity has associated with the same activities of "real" fighting such as bites, yelps, and signs of aggression. Bateson surmised that the monkeys must be accompanying these messages with *metamessages*, i.e., messages about how to interpret the accompanying message. Out of the myriad metamessages that denote the interpretation of the message—whether a bite is a real bite or just a playful nip—emerges distinct interpretative frames, such as "play" or "fighting." As Bateson (1972) puts it, "a frame is metacommunicative. Any message, which either explicitly or implicitly defines a frame, *ipso facto* gives the receiver instructions or aids in his attempt to understand the message included within the frame" (p. 188). Although he derived it from observations of animal behavior, Bateson regarded framing to be a psychologically real entity in communicative interactions more broadly, including humans.

Framing has been taken up by discourse analysts including prominent scholars in sociolinguistics (Goffman, 1974, 1981; Gumperz, 1982; Tannen, 1993a) to be the means by which we structure our experiences of communicative interaction. Goffman (1974) argues that framing gives us our sense of "what is going on" in any particular interaction, at any particular moment. We organize our implicit answers to this question in order to structurally support our experience (Goffman, 1974).

While early works on framing were based on general observations of human (and non-human) interactions, the construct was given a stronger empirical basis by sociolinguists who study language-in-use (Gumperz, 1982; Tannen, 1993a). Gumperz (1982) argued for a way of empirically tracking framing by looking for "contextualization cues" within the discourse. "By careful examination of the signaling mechanisms that conversationalists react to, one can isolate cues and symbolic conventions through which distance is maintained or frames of interpretation are created" (Gumperz, 1982, p. 7). Tannen (1993b) explored the nature of frames empirically by examining how movie-viewers described sequences of events as they are presented somewhat disconnected aspects of a story (which is all that movies are, really), Tannen (1993) argued that their sense of what was going on in the film was framed by "structures of expectation."

In summarizing the literature on framing, Tannen (1993a) brought attention to the fact that "[a]lthough the influence of Bateson's and Goffman's work has been pervasive, there have been few studies directly applying Bateson's seminal theory or

Goffman's elaborate framework in microanalytic linguistic analysis of real discourse produced in face-to-face interaction." (p. 3). Tannen & Wallat (1987) provided some such analysis when they observed the interaction of a doctor, a child patient, and the child's mother during a medical check-up. By following participants contextualization cues such as *shifts in vocal register*, they track how the participants shift back and forth between three separate frames, which they named the reporting frame, the observation frame, and the consultation frame.

These early accounts of framing have seemed to presume sets of in-place frames which all participants have access to. This could mislead one into thinking that frames are static, unchanging entities. Some researchers, however, have focused on the dynamics of frames and framing. Tannen and Wallat (1987), for example, report on the dynamics of multiple frames navigated by a parent, child, and doctor during a medical check-up. They found/argued that conflicting knowledge schema triggered shifts between frames, for example switching from the examination frame to the consultation frame to reassure the on-looking mother who thinks the child is having trouble breathing (p. 72). Although Tannen & Wallat's (1987) work seemed to presume these frames were in place and static, they did characterize the dynamics of how and why the participants move between these frames. They found that contrasting knowledge schemas amongst the participants could trigger shifts of framing.

This work on framing has also been taken up by education researchers in science education, who have theorized about and documented the dynamics of frames (Elby & Hammer, 2010; Hammer, Elby, Scherr, & Redish, 2005; Redish, 2004;

Scherr & Hammer, 2009), highlighting participants' ability to mutually shift implicitly and smoothly between multiple shared framings of their activity. Hammer, Elby, Scherr, & Redish (2005) provide a framework for student learning in physics by which students recruit conceptual and epistemological resources in which they include framing, which they take to be "the activation of a locally coherent sent of resources" (p. 9). Scherr & Hammer (2009) found evidence for these locally coherent activations of epistemological resources.

The work reported in this chapter builds upon the foundation of work reported in (Scherr & Hammer, 2009). They examined the behavior of small groups in tutorial and found that they dynamically shifted between at least four behavioral clusters, which accounted for most of the time spent in tutorial. By analyzing the discourse they found that these behavioral clusters corresponded with distinct ways the groups were epistemologically framing their behavior. For example, at times they were hunched over their desk, looking at their worksheets, and writing, with only intermittent comments to each other. This behavior coupled with the substance of their talk showed that they were framing their activity as *completing the worksheet*. At other times they were sitting up straight, making eye contact, and gesturing to each other, which is when they were framing their activity as *having a discussion.* This is the work upon which much of my dissertation will be building, and so I will be providing a more in-depth analysis below.

METHODOLOGY AND ANALYSIS

The central question of my dissertation is how groups of students in tutorial establish shared understandings of the nature of their activity. And we already know some of the dynamics by which this occurs. In (Scherr & Hammer, 2009), the authors report on the behavior of the groups in introductory physics tutorials in physics sensemaking. They found that the group switched dynamically between various ways of epistemologically framing their activity, including *having a discussion*, and *completing the worksheet*. By supplemental analysis of the students' discourse, they showed that the group-level behavioral transitions corresponded with shifts in the ways they are framing their activity. I will first report on this work, before contributing to it evidence that the nature of the discourse within one behavior mode is different in important ways than the nature of the discourse in the others. Namely, during green mode discussions there is considerably more mechanistic reasoning in their discourse.

Rachel Scherr first noticed the behavioral clusters while fast-forwarding through many hours of videotape of introductory physics tutorials, when the group-level transitions in behavior caught her eye. She then observed the behaviors and found several distinct clusters of behavior, which account for much of the time spent in tutorial. Four of these behavioral clusters are detailed in (Scherr & Hammer, 2009). The *blue behavioral cluster,* for example, consisted of the following behaviors: students hunched over, looking down at their worksheet, hands writing or otherwise quiet. The authors describe the *green behavioral cluster* as times when the group were sitting up, making eye contact, and gesturing. Coding for these behavioral modes is quite reliable, 90% before discussion, 100% after discussion.

But what *are* these behavioral modes? The blue behavioral cluster and the green behavioral cluster could both be described as collaboratively working on the tutorial. However, these behavioral clusters indicate quite distinct ways of collaborating. In the blue behavioral cluster, the students posture, gaze, and gesticulation is primarily oriented to the worksheet, which seems to imply they are framing their activity as primarily *completing the worksheet.* In the green behavioral cluster, their posture, gaze, and gestures are directly oriented to the other group members; they seem to be framing the activity as *having a discussion*. They provided three exemplary episodes of the discourse during behavioral transitions to demonstrate the different nature of the frames. In what follows I will present further evidence to support one of Scherr & Hammer's (2009) claims, namely, that one behavioral mode corresponds with higher levels of evidence of the groups mechanistically reasoning.

Discourse in green behavioral mode includes more mechanistic reasoning

In this section I summarize the findings of the research I conducted at the beginning of my graduate career, which involved applying coding schemes for both behavior (Scherr & Hammer, 2009) and mechanistic reasoning (Scherr & Hammer, 2009) to videos & transcripts of tutorial groups. By combining two independent and reliable coding systems, one for behavioral clusters and the other for mechanistic reasoning, we gain the opportunity to look for quantitative traces of the interdependence between these categorical variables by using, for instance, the chi-square test for independence. A significant result would substantiate the claims that discourse (behavior & reasoning) is different during the distinct group-level framings.

In a pilot study, Conlin, Gupta, Scherr, & Hammer (2007) analyzed 20-minute video segments from 5 introductory physics tutorials. We selected a mixture of video segments from the beginning, middle, and end of tutorials, as well as the beginning middle, and end of the semester, to protect against "boundary effects," including any potential bias arising from discourse or behavior at the beginning or end of tutorial/semester. Two independent coders analyzed the video for behavior according to the coding scheme of (Scherr & Hammer, 2009) as well as coding the transcript for evidence of mechanistic reasoning following the framework of (Russ et al., 2008). For any given segment of video, one coder transcribed and coded the mechanism, the other coding the behaviors, although these roles were alternated for each segment. I will briefly describe the coding processes, to give more of a sense of what the numbers mean.

Coding behavior—Group-level behaviors were coded for every five seconds of the video segments. An inter-rater reliability was established between three coders via the following procedure: (1) watch the clip with volume high enough just to hear the volume and pitch of speech, but low enough not to make out the content, (2) note transitions in group-level behaviors with a number, repeating numbers when the behavior seemed the same, (3) characterize the behaviors corresponding to each number in terms of posture, gesture, gaze, prosody, (4) bin numbers into related categories labeled by theory-neutral colors (red, blue, green, yellow, grey), while also allowing for mixed categories (e.g., blue-green) if it seemed like there were two different sets of behaviors co-occurring as in when the students pair-off. Such discord was quite rare, however, accounting for less than 3% of the total codes.

These procedures resulted in an inter-rater reliability of 90% before discussion, 100% after discussion. Discrepancies were resolved after discussion.

There are four primary behavior modes that regularly show up after this analysis, and they are summarized in Scherr & Hammer (2009) as well as in (Conlin et al., 2007). I will list them here along with the descriptions of the corresponding behaviors and description of the framing:

Color Code	Behavioral Cluster	Framing
Green	Sitting up, making eye contact, hands gesturing, elevated vocal register	Having a discussion
Blue	Hunched over, eyes and hands on worksheet, low vocal register	Completing the worksheet
Yellow	Fidgeting, laughing, looking around, touching face/hair	Playing around
Red	Sitting up, eyes on TA, smaller gestures, lower vocal register	Being receptive to the TA

Table 3-1. Behavior clusters, their color codes, and their corresponding frames

The five video segments were selected by grabbing any old tape, and rewinding to an arbitrary time (while keeping in mind a mixture of clips at beginning/middle/end), then choosing a 20-minute segment starting at that time. The segments were coded by the following procedure: (1) watch the clip with volume high enough just to hear the volume and pitch of speech, but low enough not to make out the content, (2) note transitions between red, blue, green, yellow, grey, and mixed behavior codes, (3) assign behavior codes to each five-second bin, rounding up if there was a transition 3-seconds or later into the bin. The four primary codes (blue, green, red yellow) account for most (86%) of the 5-second intervals. Including the mixed blue-green code then accounts for 97% of the time.

Code	frequency	% time
blue	366	32%
blue-green	129	11%
green	289	25%
red	277	24%
yellow	63	5%
other	34	3%
total	1158	100%

Table 3-2. Relative frequencies of behavior codes for each 5-second interval of the video clip

Coding Mechanistic Reasoning—Two independent coders analyzed the transcripts of the video segments based on the framework of Russ et al. (2008). This framework is based on work in philosophy on the nature of mechanistic accounts in science (Machamer, Darden, & Craver, 2000), which has characterized a mechanism in the following way (p. 3):

> Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions.

Russ et al. (2008) argue that students show evidence that they are reasoning mechanistically whenever their talk contains some aspect of mechanisms, whether it is identifying the identities involved or how they act in order to bring about changes. They built a coding scheme by analyzing student discourse for the presence of the following aspects of mechanisms, in order of the quality of evidence of mechanistic reasoning: (1) describing target phenomenon, (2) identifying set up conditions, (3) identifying entities, (4) identifying actions, (5) identifying properties of entities, (6) identifying the organization of entities, and (7) chaining.

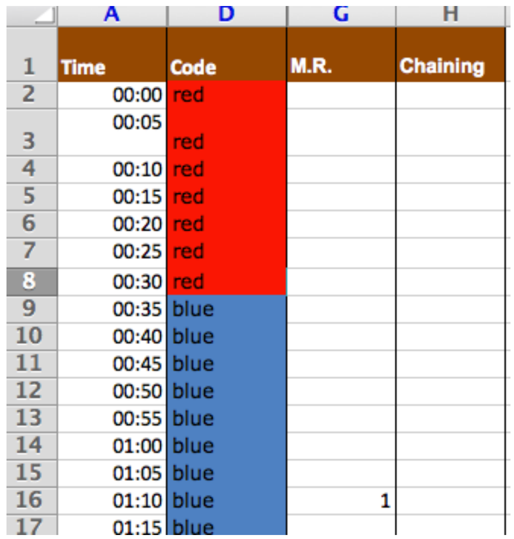
The highest mechanistic reasoning code (7), *chaining*, involves piecing together several of the other elements of mechanistic reasoning in order to make a prediction about how things will be or about how things must have been in the past. It is a special code in that it is the most complete of students reasoning mechanistically. An example of chaining would be when Bree is talking about a roller-coaster car as it goes around a loop-the-loop and she describes why the force of the track on the car has to be downwards when the car is upside down at the top of the loop: “it [the force of the track] has to be pressing in, to keep it [the car] from like, shooting out.” She is reasoning about entities (the force of the track, the car) and what they are doing (pressing in) so she can predict what will or will not happen (the car will be kept in rather than shoot out).

	B	F	G	H	I
1					
2	Time mm.ss	speaker	utterance	MR	chaining
3	0	TA	...help you get started...[inaudible]...So, [??] at the bottom this week instead of um you guys were doing the experiment individually in your groups, we're gonna do it as sort of a class demonstration all together cause we have only one set up. So when you get to that point at the bottom of the page we're gonna try to kinda hold off and wait till everybody gets there.	0	
4	0.22	S1	Omigod	0	
5		S4	Oh, just for this?	0	
6		S1	Just for this or did you mean...	0	
7		TA	No, just for this.	0	
8		S4	Oh, that sucks.	0	
9		S2	I knew that [inaudible] is she gonna have that worksheet...	0	
.0		S1	Hey, I was close.	0	
.1	0.39	S4	I wonder how we did on the last lab.	0	
.2		S1	Oh yeah...hopefully it's better than how I did on the first homework...okay...[reading]...according to common s...	0	
3	0.57	S3	Yeah, I have some trouble understanding.	0	
		S4	[reading] according to common sense, which force is greatest	0	

Figure 3.1—Coding the transcript for mechanistic reasoning, and chaining specifically.

Two independent coders trained by analyzing the same transcript for mechanistic reasoning, agreeing on 87% of the mechanistic reasoning codes including chaining. Then they transcribed the various 20-minute video segments of the students working in tutorial and coded them according to the above framework.

Analyzing the intersection of behavior and reasoning—Two independent coders analyzed the video for behavior and the transcript for mechanistic reasoning. Every five seconds of the video was coded for the behavior mode, as well as the presence of any evidence of mechanistic reasoning and of chaining in particular.



	A	D	G	H
1	Time	Code	M.R.	Chaining
2	00:00	red		
3	00:05	red		
4	00:10	red		
5	00:15	red		
6	00:20	red		
7	00:25	red		
8	00:30	red		
9	00:35	blue		
10	00:40	blue		
11	00:45	blue		
12	00:50	blue		
13	00:55	blue		
14	01:00	blue		
15	01:05	blue		
16	01:10	blue	1	
17	01:15	blue		

Figure 3.2—Coding the behaviors every 5 seconds.

Of all the mechanistic reasoning codes, more than half (53%) fell within the green behavior mode, when students are sitting up, making eye contact, and gesturing. Moreover, the vast majority (81%) of all the chaining occurred in the green behavioral mode:

Behavior Code	count	% time	M.R. Codes	% M.R.	Chaining codes	% chaining
blue	366	32%	57	18%	3	6%
blue-green	129	11%	34	11%	2	4%
green	289	25%	165	53%	39	81%
red	277	24%	47	15%	2	4%
yellow	63	5%	4	1%	0	0%
other	34	3%	3	1%	2	4%

Table 3-3. The frequency of each behavior mode, along with the frequency of mechanistic reasoning and chaining codes

The proportion of mechanistic reasoning codes in green mode (165/310 = 53%) were over twice the proportion present in any other behavior mode, despite the fact that students spent more time blue mode, and approximately the same amount of time in red mode.

One way of clearly illustrating the increased density of mechanistic reasoning codes during green mode is to split the time in tutorial into rectangles with areas proportional to the time spent in each mode. Then we can represent each instance of a mechanistic reasoning code as dots in these squares—each open circle represents a mechanistic reasoning code, while closed circles represent instances of *chaining* codes. Due to space constraints, I only include the square for a single 20-minute video segment.

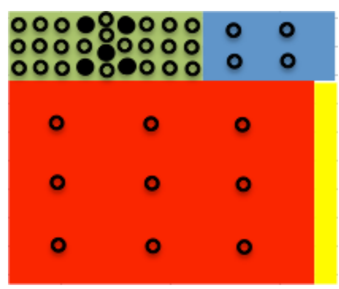


Figure 3.3—The areas are proportional to the amount of time in a behavior mode. Circles represent mechanistic reasoning codes, with solid dots being chaining codes.

We can do a statistical test for whether this disproportionate amount of mechanistic reasoning codes within green mode is due to chance by using the χ^2 test for independence. The data here is categorical, mutually exclusive, and exhaustive if we count the presence or absence of mechanistic reasoning codes and likewise for codes for the green behavioral mode. There are several ways to implement this test. The most straightforward way is to proceed by counting all the 5-second intervals that were coded as being green, along with whether they contain a mechanistic reasoning code. The frequencies for the cumulative codes of all five 20-minute video segments are summarized in the contingency table below:

Counting Behaviors	5-sec Intervals Coded as Green Mode	5-sec Intervals NOT Coded as Green Mode	TOTALS
5-sec Intervals Containing Mechanistic Reasoning Codes	165	145	**310**
5-sec Intervals NOT Containing Mechanistic Reasoning Codes	124	724	**848**
TOTALS	**289**	**869**	**1158**

Table 3-4. Contingency table for behavior codes and mechanistic reasoning codes. Observed test statistic 180.63 > Critical Value 6.63

Setting $\alpha = .01$ as the significance criterion, we can now test for whether this disproportionate amount of mechanistic in green mode is due to chance by using the χ^2 test for independence. The observed frequency of green mode codes that contained mechanistic reasoning (165) was higher than the expected value based on row frequencies (77). In addition, non-green behavior modes contained a much lower frequency of mechanistic reasoning (145) than the expected value (232). The difference is statistically significant ($\chi^2(1, N = 1158) = 180.63$, $p < .01$) so we can infer that we are more likely to have mechanistic reasoning codes when the behavior mode is green. Further analysis reveals that the effect size is

$w = \sqrt{\sum_{i-1}^{k} \frac{\left(P_{1i} - P_{0i}\right)^2}{P_{0i}}} = .39$, which for the χ^2 test for independence we can describe as slightly above a medium effect size (Cohen, 1992, 1988). This value indexes the difference between green modes and non-green modes in terms of likelihood of the presence of mechanistic reasoning codes. Given *alpha* (.01), *N* (1158), and *w* (.39) allows us to determine statistical power, which in this case is approximately .80, enough to detect even small effect sizes (Cohen, 1992).

Now we can test whether there is a relationship between the green behavior mode and the highest mechanistic reasoning code, chaining. The proportions seem more dramatic for chaining than the mechanistic reasoning codes—81% of all the chaining happened in the green mode. A χ^2 test for independence shows that this difference is significant, $\chi^2(1, N = 1158) = 84.73$, $p < .01$. At .27, the effect size is medium, and the power is essentially 1, enough to pick up even a small effect.

	GREEN	~GREEN	TOTALS
Chaining	39	9	48
~Chaining	250	860	1110
TOTALS	**289**	**869**	**1158**

Table 3-5. Contingency table for green mode behavior codes with chaining codes

Since we are counting 5-second time intervals in the above two chi square tests, the result already correct for the amount of time spent in green vs. non-green behavioral modes. We can thereby rule out the possibility that it is just due to the students having *more time* in green without the talk in green mode being any more mechanistic. However, a worry that remains is the result could still be due to the groups just *speaking more* during green mode, without that talk being any more mechanistic. We can explore this question by counting utterances (i.e., conversational turns) rather than time intervals.

Each *utterance* is coded for whether it contained evidence of mechanistic reasoning. The utterance is also coded for whether it occurred during a green mode or not. Counting by utterance is more labor intensive, and so due to time and space constraints I will have to restrict this analysis to a single 20-minute tutorial video segment[9]. The frequencies for this segment are summarized in the contingency table below:

Counting Utterances	Utterances during Green mode	Utterances NOT during Green mode	TOTALS
Utterances Coded as Mechanistic Reasoning	44	18	62
Utterances Not Coded As Mechanistic Reasoning	40	87	127
TOTALS	**84**	**105**	**189**

Table 3-6. Contingency table for utterances coded as mechanistic reasoning and utterances made during green mode.

Once again setting $\alpha = .01$ as the criterion for statistical significance, we can see if these frequencies could be expected based on chance alone. There are more mechanistic utterances during green modes (44) than would be expected based on chance (28), and fewer mechanistic utterances during non-green modes (18) than expected (34). The difference is significant according to the χ^2 test for independence, $\chi^2(1, N = 189) = 26.29$, $p = 2.94\text{x}10^{-7}$. We can conclude that utterances made during green mode are more likely to be mechanistic. The effect size,

$w = \sqrt{\sum_{i-1}^{k} \frac{\left(P_{1i} - P_{0i}\right)^2}{P_{0i}}} = .39$, was slightly above a moderate effect size for this test.

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[9] This segment was selected from the Sparrows 3rd tutorial.

Further analysis revealed that the power is above .80 and that sample size of 189 is indeed sufficient to detect a medium effect size (Cohen, 1988, 1992).

Future work would have to do this analysis of counting by utterance for the remaining video segments. This segment can only provide a plausibility argument. However, there is no reason to suspect that this strong connection between the mechanistic quality of statements and the green mode behavior is unique to this one segment. Having corrected both for time spent in green mode, as well as the number of utterances in green mode, there still remains another possible worry to explore—utterance length. It could be that mechanistic reasoning, and chaining in particular, tends to happen when the utterances are longer. While it is certainly plausible, there is reason to doubt it—there are many short utterances that are coded for mechanistic reasoning and even chaining, e.g., when students collaboratively build on each other's statements. This should be explored in future work. In any event, this is a worry that does not cut into my central claim, however, which is that the students are framing their activity differently during green mode.

What To Take Away from the Quantitative Analysis—We can infer that whether or not an utterance is mechanistic is correlated with whether it is uttered while the group is in the green behavioral mode, i.e., sitting up, gesturing, making eye contact, etc. This substantiates the claim that the changes in group-level behaviors correspond with changes in the group's epistemological framing of the activity, given the changes in behavior and in discourse. In this case, the data supports the claim that when in green mode, the students are approaching the activity with a different epistemological framing than their activities during other modes of behavior. A rough characterization could describe this framing as *having a discussion*, but this does not exhaust the characterization of the epistemological framing of a group. The *discussion* frame must involve different amounts of talking about the *mechanism* than the groups' other ways of framing their activity. But it would be oversimplifying to characterize the green mode as *discussing mechanism*, since they also discuss other matters during that time, such as discussing non-mechanistic tutorial questions as in "what are the potential benefits of discussing your mistakes" and the like. To examine the nature of discourse during green modes requires a closer analysis of the substance of their speech and the structure of their behaviors, which I will provide in the next chapter.

Scherr & Hammer (2009) as well as Conlin et al. (2007) both present evidence that some of these shared ways of framing their activity are more conducive for collaborative sensemaking than others. For instance, there is a disproportionate amount of evidence of high-level mechanistic reasoning during the *green* behavioral cluster, which is when the groups were framing their activity as *having a discussion*. Since reasoning about physical mechanism is a central component of sensemaking in physics, the behavioral clusters can act as a powerful tool for selecting for clips that contain evidence of collaborative scientific sensemaking.

Before relying too heavily on the connection between the green behavioral cluster and mechanistic reasoning, I must close an interpretational loophole the previous analyses have left unresolved. Namely, the correlation is still open to an alternate interpretation: perhaps the increased evidence of mechanistic reasoning during the discussion frame is simply due to the fact that the groups are *talking more* during discussion. In this chapter, I will present a quantitative analysis that addresses this concern by correcting for time spent in each behavioral mode, and another that corrects for the number of utterances spoken within each frame. The end result is that the discourse during the discussion frame contains more evidence of mechanistic reasoning not just because they are talking *more*; it is rather that they are talking *differently.* Specifically, an utterance is much more likely to contain mechanistic reasoning if it is uttered during the discussion frame.

CHAPTER CONCLUSIONS

In this dissertation, I am exploring the processes by which groups of students build shared understandings. In this chapter, I have focused in on one rather particular sort of shared understanding—the groups' shared understanding about the nature of what they are doing. This is what discourse analysts have referred to as their *framing* of their activity. Frames, according to Goffman (1974), provide our implicit answer to the question to which we are constantly asking ourselves and establishing for each other: *What is it that is going on here.* I have reported on how student groups in physics tutorials frame their learning activity in at least four distinct ways, which they transition between as group. There are times when they are framing their activity as *having a discussion* and times when they are framing it as *completing a worksheet*.

I also presented evidence that the students' speech is much more mechanistic when they are framing their activity as *having a discussion*. When they are having a discussion, *of course* there is going to be more mechanistic speech. But this result holds even when correcting for both the amount of time spent in each mode and the amount of utterances. So it is not that they are just talking *more* during green mode, they are talking *more mechanistically*. And talking more mechanistically is just the sort of thing we want them to be doing, if we want them to be doing inquiry into physics.

While the analysis in this chapter establishes *that* the groups build shared understandings of what they are doing, it does not address the question of how they accomplish this. Nor does it address how these shared understandings may develop over time. I will address each question, in turn, in the next couple of chapters. In Chapter 4, I will examine how the groups manage to construct a shared space where they feel comfortable introducing and evaluating their ideas. In Chapter 5, I follow these same groups through the rest of the semester to examine the longer-term dynamics of their sense of what it is they are doing together.

Chapter 4: Making Space to Sensemake

INTRODUCTION

In the first chapter of this dissertation, I identified two central research aims: (1) to give an empirical account of how groups of tutorial students come to share an understanding that they should be collaboratively making sense of physical phenomena, and (2) to explore the longer-term dynamics of how this understanding develops throughout the semester. In Chapter 2, I reviewed literature on scientific argumentation and discourse analysis that suggests that in order to build these shared understandings, the tutorial students must manage to make repairs of understanding while also making repairs of affect. In Chapter 3, I reported on research that establishes *that* the groups are able to build shared understandings of their activity, but this research does has not addressed the question of how they build these shared understandings in the first place.

In Chapter 4, I address one of the central aims of the dissertation by giving an empirical account of how groups of tutorial students come to share an understanding of the nature of their activity. Through an analysis of the behavior and discourse of three tutorial groups' first few discussions in tutorial, I describe the processes by which they build a shared understanding of the nature of collaboratively making sense of physical phenomena, and this question. Through this analysis I demonstrate some of the linguistic and interactional resources by which the students manage the epistemological and affective dynamics in building a shared sense of what it is they are doing in tutorial. I identify one resource in particular that students use to manage the epistemological and affective dynamics simultaneously—epistemic distancing. By distancing themselves from their claims, through hedging and other varieties of footing shifts, the students soften their stance in such a way leaves space for the groups to sensemake. For instance, I show that through hedging and through ironic shifts of footing, the students are able to take the tutorial seriously, but not *too* seriously. This allows them to ease away from *reading what they wrote* and towards *saying what they think.*

In what follows, I will first discuss the theoretical foundations for this analysis, pulling from research in the philosophy of science and science education that highlights the epistemological significance of students' modifications of their claims through hedging. Then I will analyze three tutorial groups' early interactions to show how their management of epistemic distance helps them to enter their first discussion of the semester (Part I) as well as their first collaborative scientific sensemaking discussion of the semester (Part II).

THEORETICAL FRAMEWORK

Making space to sensemake

Many scientists and philosophers have characterized science as a delicate balance between the generation and evaluation of ideas (e.g., Japp, 1898; T. S. Kuhn, 1977). Research on students' learning of science through inquiry has also highlighted this tension in scientific argumentation and sensemaking discussions (Duschl, 2008; Ford, 2008; Kelly, 2007). This research has revealed that these two processes of idea generation and evaluation are not independent, but rather remain in constant interplay. Ford (2008) describes the construction and the critique of claims as complementary aspects of students' grasp of scientific practice. Duschl (2008) and Kelly (2007) highlight the social and affective tensions that link the creative and critical processes within scientific argumentation and sensemaking.

When a student's (or a scientist's) ideas are corrected or rejected there can be negative social and affective repercussions, including loss of face, embarrassment, and frustration. These in turn can threaten shut down scientific inquiry, for instance, by preventing the future introduction of ideas. This tension is present at the level of scientific communities, where scientists put their reputations at risk with the introduction of new evidence and explanations. If those ideas are rejected, the scientists who introduced them can find their reputations in jeopardy.[10] In science classroom discussions, these tensions manifest in the students' making repairs of understanding while managing the affective consequences of such repairs.

Duschl (2008) and Kelly (2007) each draw attention to the social and affective nature of the connection between creative and critical processes of scientific argumentation and sensemaking. Both authors note that the disagreement required for scientific argumentation can result in negative social and affective consequences

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[10] This was the case for Dan Shechtman, for example. Shechtman recently won the Nobel Prize in chemistry for the discovery of quasicrystals despite idea's initial rejection, which caused long-lasting damage his reputation. Shechtman was expelled by his research group after his discovery, and was ridiculed by leading chemists such Linus Pauling, who quipped: "There is no such thing as quasicrystals, only quasi-scientists."

that can shut down the discussion. Both argue for the need for students to develop norms by which they can make their thinking visible while also remaining open to having those ideas assessed and refined, noting that the processes by which groups establish these norms are not well understood.

In this chapter, I contribute to research on how groups establish norms of interaction that enable them to balance the epistemological and affective dynamics of scientific argumentation and sensemaking. By analyzing three tutorial groups' behaviors and discourse during their first few discussions of the semester, I demonstrate some of the linguistic resources by which they balance making repairs of understanding with making repairs to affect. In what follows, I develop the theoretical framework for identifying one such resource, which I find plays a major role in the group's sensemaking dynamics: the downgrading of epistemic stance through hedging, deferring, and other shifts of footing.

In what follows, I will first show how literature from philosophy of science and from science education research supports the view that the management of appropriate downgrading of claims is a key aspect of sophisticated scientific discourse. Then I will review research from discourse analysis that develops theoretical and analytical tools for identifying when and how people modify their epistemic stance in conversation, through shifts in footing such as hedging or even through the use irony.

Managing epistemic commitments in scientific discourse

Philosophers of science have identified the appropriate use of caution in making and evaluating claims as a key element of sophisticated scientific discourse

(Lakatos, 1980; Laudan, 1981; Whitt, 1990). One reason for this is that at any given time there are many theories (e.g., string theory) and experimental results (e.g., faster-than-light neutrinos) whose epistemic certainty is in limbo. Theories that have been rejected by the scientific community at one time can still make a comeback, as was the case in the particle theory of light (Lakatos, 1980) and in the pursuit of the hidden variables of quantum mechanics (Baggott, 1992; Bohm, 1952). These historical cases of theories lying within the 'nether region' between discovery and acceptance suggest that science could not proceed if scientists only pursued theories they believed in (Laudan, 1981, p. 174; see also Whitt, 1990). For this reason, Laudan (1981) distinguishes between *the pursuit* of a theory and *belief in a theory*, arguing for their equal status as rational forms of scientific appraisal.

Laudan's argument for the rationality of theory pursuit without belief identifies just one of the manifold ways scientists epistemologically manage their commitment to theoretical and experimental claims. For instance Lakatos (1980) has pointed out that scientists orient themselves distribute their trust unequally among the components of a theory, with some claims forming core beliefs while others form a 'protective belt' of auxiliary assumptions that can be subject to change. As Feynman has put it, "scientific knowledge is a body of statements of varying degrees of certainty—some most unsure, some nearly sure, but none absolutely certain" (Feynman, 1988). This variation in epistemological status of the various laws and theories requires scientists to constantly manage their epistemic stance within a whole network of theoretical commitments. Researchers in discourse analysis have begun to study how scientists manage their epistemic commitments through discourse moves such as hedging (Schröder & Zimmer, 1997; Varttala, 1999).

Given the importance in scientific discourse of maintaining an appropriate distance from one's claims in scientific discourse, researchers in science education have identified the appropriate use of caution in making and evaluating claims as an important aspect of their epistemological understandings in learning science. Several researchers in science education have analyzed students' discourse to show how they manage their commitment to their claims through hedging (diSessa, Elby, & Hammer, 2003; Kirch & Siry, 2010). diSessa, Elby, & Hammer (2003) argue that a student's choice of when to hedge, and when not to, is an "epistemologically loaded" discourse move that can shed light on a student's conceptual and epistemological understandings in physics.

My dissertation contributes to this work by identifying several ways students index their epistemic commitment to their claims and stances within collaborative scientific sensemaking. I also examine the influence of the students' hedging on the dynamics of sensemaking discussion, finding that it plays both a role in both the epistemological and affective dynamics. By hedging their claims the students are able to monitor the sources and certainty of their claims, and by softening their stances the students they can protect themselves from the affective sting of having their positions challenged, refined, or rejected. In this way, hedging can help students maintain a space where they feel safe to introduce and publicly evaluate their ideas. In the next section, I draw from research on discourse analysis to identify some of the ways students in tutorial epistemically downgrade their stances in ways that help create a safe space to sensemake.

Epistemic Distancing Through Shifts Of Footing—In Chapter 2, I reviewed research on discourse analysis that revealed how speakers in conversation modify their stances through shifts of footing. This research has identified several discourse markers by which speakers can upgrade or downgrade their epistemic commitments (e.g., "I guess…"). Researchers on stance have also identified paralinguistic channels by which participants in conversation can convey their epistemic stance, including tone of voice (Ward & Hirschberg, 1985) and even the physical positioning of the body (Goodwin, 2007a).

In Chapter 2 I also highlighted one way that students can modify their epistemic stance in conversation: through *shifts in footing* (Goodwin, 2007b). The notion of footing was introduced by Goffman (Goffman, 1979; Goodwin, 2007a) to characterize the subtle ways that speakers can distance themselves from "meaning what they say." Goffman discussed hedgers and qualifiers as a means of "introducing distance between the figure and its avowal" (p. 148), thereby changing the relationship a speaker has with their statement. This is what Goffman refers to as a *shift in footing*. In his words, *"[w]hen we shift from saying something ourselves to reporting what someone else said, we are changing our footing."* (1979, p. 151). By hedging, quoting, and other shifts in footing, speakers can signal whether they are the author of a claim (the person who came up with it), or just the messenger.

Shifts in footing can be used to epistemically upgrade or downgrade claims, for instance by *deferring* (e.g., "research has proven…") or by *hedging* (e.g., "I guess…") (Clift, 2006; Kärkkäinen, 2003, 2007). I use the term *epistemic distancing* to refer to a shift in footing that softens the speaker's stance. Through epistemic distancing, students can reduce their epistemological and affective stake in their statements in ways that shield students the affective risks of taking a stance, thereby facilitating the groups' construction of a safe space to introduce and evaluate their ideas.

In the data analysis section of this chapter, I will present video analyses that show how three groups rely on epistemic distancing as a resource to manage conceptual, epistemological, and affective tensions in making a safe space to sensemake. It is through managing these tensions that the groups are able to maintain a balance between the generation and evaluation of ideas in order to make sense of physical phenomena.

The data analysis is divided into two parts. In Part I, I analyze how three tutorial groups (the Bluebirds, the Sparrows, and the Ospreys) each get into their first discussion of the semester. I show how each group is able to build a shared understanding of their activity as *having a discussion*. They accomplish this, in part, through their use of epistemic distancing. In Part II, I analyze how each group comes to understanding their activity in a way that involves collaboratively making sense of physical mechanisms through discussion. I show how the how this understanding is aided by the students' epistemic distancing as well.

DATA ANALYSIS, PART I – HOW A DISCUSSION IS BORN

In Part I of my analysis of the tutorial groups' early interactions, I examine each group's 1st discussion of the semester. Through a close analysis of their coordinated behaviors and reasoning, I describe the processes by which the students build a shared framing of their activity as having a discussion. I also point to the precursors of collaborative scientific sensemaking in each group's first discussion. This leads to Part II of this analysis, where the central focus is on how the groups come to frame their activity as collaboratively making sense of physical phenomena.

All three groups get into their first discussion of the semester in response to the instructions of the first tutorial question. As shown in Fig 4.1, the first question asks students to reflect on their learning. Specifically, it asks them how thinking about their mistakes may help them learn physics.

Since reflecting on the purpose of an activity can help you get more out of it, let's start with this:

A. (*Answer individually*) What do you see as potential benefits of explicitly thinking and talking about the mistakes you make while working through these activities? If you think dwelling on your mistakes won't be particularly helpful, explain why not.

Figure 4.1—Part I.A. of Tutorial 1 asks them to reflect on the potential benefits of thinking and talking about mistakes they make.

Part B of the first question asks them to discuss their answers to part A. It also asks them to note any differences amongst the groups' answers (see Fig 4.2).

B. Discuss your answers with your group. If anyone gave part of an answer significantly different from yours, write a one-sentence-summary of that opinion here.

Figure 4.2—Part I.B. of Tutorial 1 asks them to discuss their Reponses to Part I.A with their group

As I will discuss in what follows, all three groups get into their first discussion in response to part B, where they are asked to discuss their answers. At the same time, all three groups show signs of resisting this activity. There is a wide variability amongst the groups in how they take up this discussion, which shows that "following the instructions" is an interactional achievement that is not to be taken for granted. In Part I, I show how differences amongst students' use of epistemic distancing can help explain this variability in their first discussion. In Part II, I show the students' and TA's management of epistemic distancing helps each group to construct a safe space to sensemake.

The Bluebirds' 1st discussion—"I guess we should…'discussss our answersss'"

After the TA's introduction to the tutorials, the Bluebirds start the tutorial silently focused on their worksheets. After a few minutes, the group suddenly transitions to a new set of shared behaviors. They go from being hunched over their worksheets and looking down as they write, to sitting up, making eye contact, speaking, and gesturing. This shift is what Scherr and Hammer (2009) describe as a transition between two ways of framing their activity, from *completing the worksheet* to *having a discussion*. They engage in the discussion for about one minute before turning back to the worksheet. How do they accomplish this group level shift in how they are understanding their activity? I will discuss the behavioral transition and then analyze the discourse surrounding it to gain on insight on how and why it happened.

Figure 4.3—The Bluebird's first transition from completing the worksheet to having a discussion

Behaviorally, each student orients to the group space one at a time over a span of about thirty seconds. Deirdre transitions first. As she finishes Part A she sits back, lifts her hands away from her tutorial worksheet, and looks up. This constitutes an example of what Scherr & Hammer (2009) call a *bid* for a change in activity. After the last student orients to the group space Deirdre hedges as she suggests the group's

DEIRDRE: I guess we should...whatdidwehavetodo?
BREE: *(in a mocking tone)* "Discusssss our answersss..."
AMANDA: I'm sure we all wrote the same thing *(laughs)*
DEIRDRE: We could just **read** it to each other Idunno, to see...
BREE: Well...
AMANDA: What'd you write, Bree?
BREE: *(smiling, in a mocking tone)* I wrote, "Thinking about your

next action.

mistakes helps you realize where you went wrong in your thinking (Amanda gestures) and what led you to think that way (Bree gestures) to begin with." (laughter)
AMANDA: (laughing) I wrote exactly the same thing.

Deirdre starts the discussion by "calling the question" when she says "I guess we should…" but leaves it open what it is they should do. She asks, "whatisitwehavetodo?" and looks down at her worksheet, which she points at with her pen as she reads.

Bree follows Deirdre's gaze downward and looks at her own worksheet, reading in a sort of mocking tone, "Discussss our answersssss." Bree's move sends the signs of both compliance and resistance, an ambiguity created by reading the instructions while also possibly mocking them. Amanda offers further resistance to discussion by saying, "I'm sure we all wrote the same thing," which would apparently obviate the instructions of the tutorial. Deirdre manages this ambiguous landscape of stances towards following the instructions by a sort of compromise, "We could just **read** it to each other Idunno, to see…" Reading out loud is not exactly discussing, but it is a way for the students to follow the letter of the tutorial instructions, if not the spirit. This move turns out to be a critical one as they enter an alignment of engaging with the tutorial. In this way, the Bluebirds work out a system of taking the tutorial seriously, but not *too* seriously.

This move to read out loud also capitalizes on the turn-taking structure of discourse. By agreeing to read their answers out loud to each other, every group member gains access to an opportunity to "have the floor." Bree takes the floor first, and she uses the same ironic shift in register to deliver her own response as she did the tutorial. Amanda "plays along" by making a gesture that seems to say, "but of course!" and laughing. Bree's move here is somewhat self-deprecatory in that she is mocking her own response. This is also an ambiguous message of following the tutorial while at the same time mocking it. Amanda replies, "I wrote exactly the same thing" in a similar register, a move which in this case serves as a proxy for her turn at having the floor, obviating the need to read her own response.

Carmelle goes last, but since Bree is still commenting on her turn there is some overlapping speech that precipitates the repair of the turn-taking structure:

CARMELLE:	I just put that it um,
BREE:	...silly.
CARMELLE:	Oh, you still goin' I'm sorry
BREE:	Oh nonono I'm done
CARMELLE:	I was just gonna say it comforts others in knowing that they too may have made the same mistakes, so you don't feel like you're alone, (Bree nods) and um, I also said it kind of fosters better reasoning because /if you can/ reason through you mistakes then you can-
TA ROSSLYN:	(off camera) Real quick, guys, I 'm sorry to inter- I need to explain to you about how to do the experiment for this one...

Carmelle recognizes the fact that Bree is still talking and that she may be intruding on Bree's turn. She had apparently understood that she was next, but there were problems with that understanding. Bree repaired the turn overlap by letting Carmelle she was in fact not interrupting: "Oh nonono I'm done." Carmelle then goes and she starts reading her response speeding up her pace after the repair. She looks up as she shifts from reading what she wrote to saying what she thinks. Carmelle gets interrupted by the TA who starts making an announcement to the class. The TA accompanies her interruption with repair of understanding that the interruption is potentially cutting into what the TA's want them to be doing. That is the end of their first discussion, as the TA's take a few minutes to explain how to use the motion detector for the upcoming parts of the tutorial.

How the Bluebirds Got Into Their First Discussion—In part, the Bluebirds get into the discussion by following the instructions and thereby relying on the intentions of the tutorial writers. This is no simple matter, because there are many ways of interpreting the tutorial instructions of "discuss your answers with your group," not all of which align equally well with the intentions of the tutorial. This is a group achievement that it is worthwhile to understand based on the details of each group's interaction.

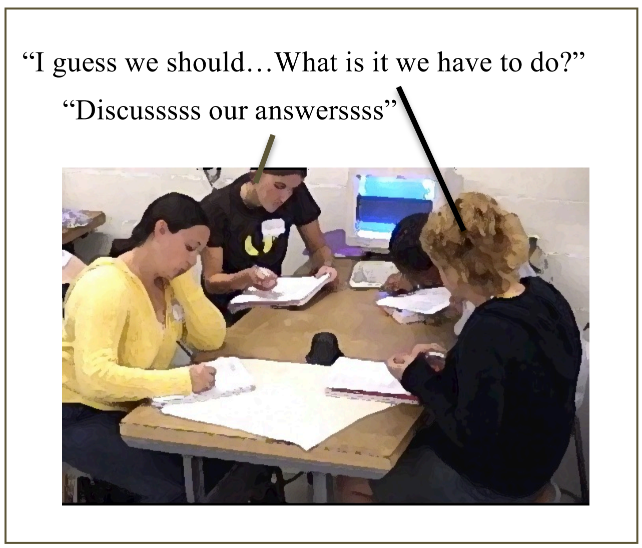

Figure 4.4—Both Deirdre and Bree use epistemic distancing to suggest the group's next move according to the worksheet.

The Bluebirds used epistemic distancing in ways that helped them take the tutorial question seriously, without taking it *too* seriously. Deirdre makes a bid to change group's activity, but softens her stance first by hedging and then by turning it into a question. Bree answers Deirdre's question, but in a mocking tone with exaggerated pronunciation. This move constitutes an ironic shift in footing in which

Bree distances herself from the content of her suggestion to discuss their answers (Clift, 1999; Goffman, 1979). Deirdre introduced further distancing from the task by suggesting they read their responses. This move stabilizes their discussion, since by taking turns the Bluebirds are able to introduce more ideas about how discussing mistakes can be beneficial for learning. By taking turns and by softening their stances through hedging and ironic shifts of footing the Bluebirds ease away from *reading what they wrote* and towards *saying what they think*. In Part II I show how this move proves to be a foundational step in the Bluebirds' sensemaking dynamics.

The Sparrows' 1st discussion—"Whatever…next!"

Like the Bluebirds, the Sparrows switch as a group from being hunched over, oriented to their worksheet to sitting up and orienting to the group. The entire transition takes thirty seconds.

Figure 4.5—The Sparrows first transition into the Green mode behaviors

Daria is the first to speak. She does not comment explicitly on what they should do (unlike the Bluebirds), but rather dives right into discussing her answer. She does so in a way that is an apparent attempt to obviate anyone else from having to take a turn sharing their answers, a move which Alan and the others then get behind. Alan closes the brief discussion with a dismissive comment, "Whatever…next!"

CHRISSY:	(laughs)
DARIA:	So...okay.../we talked about how/ you can learn from your mistakes /pretty much/ yeah
ALAN:	Yeah I think everyone said "learning from your mistakes," right?
DARIA:	Yeah
BRANDI:	Right
CHRISSY:	(laughs)
DARIA:	/pretty much okay/
ALAN:	Whatever...next!

How The Sparrows Got Into Their 1s Discussion—Like the Bluebirds, this group has also entered into their first discussion by following the instructions, but the Sparrows engage with the substance of the question much more superficially than do the Bluebirds. Nobody in the Sparrows actually reads their response, which was a move that helped Bluebirds distance themselves from the tutorial question while still engaging with it. In the Sparrows, the group seems to cohere around a dismissive attitude towards the tutorial question and their need to discuss it. At this point, the group could be in danger of aligning against the grain of the tutorial's goals. They will continue on in this direction until a TA intervention I will discuss in Part II.

The Ospreys' 1st discussion—"It's been proven that you learn from your mistakes"

Like the Bluebirds and the Sparrows, the Ospreys orient to the group space after an extended period of focusing on their individual worksheets.

Figure 4.6—The Ospreys' first transition into the Green mode behaviors

Adam is the first to transition in his behaviors when he puts his pen down and looks up at the computer screen. He apparently finishes Part A about a minute before anyone else. Towards the end of this minute, Brad makes a disparaging comment on the tutorial question right before Cathy looks up and starts the discussion.

BRAD:	PShshss this is very...condescending
CATHY:	What were...your reasons?
DEVIN:	/S'just/ allows you to better understand :: the way **you** thought about it,=
CATHY:	I said...if you
DEVIN:	=versus the correct way, /so you can sorta/ be able to assess the situation better next time.
CATHY:	Yeah, if you- can catch your mistakes you might notice like a pattern /of/ what you- like, what topic you're /not/ understanding
ADAM:	It's been proven that you learn from your mistakes.
BRAD:	M'yah

How The Ospreys Got Into Their 1st Discussion—Despite Brad's disparaging comment, the group enters the discussion by tacitly agreeing to follow the instructions. Cathy and Devin each share their ideas about how discussing mistakes can help them learn, while Adam states matter-of-factly: "It's been proven that you learn from your mistakes." This statement constitutes a shift in footing that epistemically upgrades his stance. This statement seems to shut down the conversation, perhaps because Adam is deferring to experts instead of offering more ideas about *how* talking about mistakes can help.

Summary of part I—Reflection on the groups' 1st discussion

In Part I of my analysis, I examined three tutorial groups' 1st discussion of the semester in order to describe the processes by which they first got into a discussion. I found that all three groups entered their first discussion in response to the worksheet instructions. I also found variability across the groups in how they interpreted these instructions, which highlights the fact that "following the instructions" is a mutual achievement and not to be taken for granted. The Bluebirds decided to each read their response, a move that lengthened their discussion and enabled them to get more ideas on the table. In contrast, the Sparrows were generally dismissive and do not discuss much at all. They bypass the turn-taking format by agreeing that they all put "learning from your mistakes." The Ospreys' first discussion is more substantial than the Sparrows', with Devin and Cathy talking about ways talking about your mistakes can actually help you learn.

The groups' variability in taking up the discussion can be partly explained through the students' management of epistemic distance. In a sense, the Ospreys used too little epistemic distancing; the discussion shuts down when Adam states, matter-of-factly, "It's been proven that you learn from your mistakes." The Sparrows, on the other hand, use too much. By saying, "I think we all put 'learning from your mistakes,'" Alan shifts his footing in a way that epistemically distances himself from the activity and precludes further discussion from the others when they implicitly agree. To a much greater extent than the other groups, the Bluebirds' were able to make space for sensemaking about the substance of the tutorial question.

Through their use of hedging ("I guess we should…") and ironic shifts of footing ("discusss our answerssss…") in a way that enabled them to ease from "reading what they wrote" to "saying what they think."

Although the first question is not about making sense of physical mechanisms per se, there is variability across the groups in how the groups take it up. Although the Sparrows are generally dismissive of the first question, the Ospreys and Bluebirds each engage with the substance of the first questions that show signs of collaborative scientific sensemaking. In the Ospreys, Cathy and Devin tried to make sense of the mechanism by which talking through your mistakes can help you to learn physics, in alignment with the tutorial goals. In the Bluebirds, the group's activity goes from *reading what they wrote* to *saying what they think*, a shift in footing that is a precursor to framing their activity as collaborative scientific sensemaking.

Although these first discussions contain hints of collaborative sensemaking, the question remains as to how the groups build a shared framing of their activity as collaborative making sense of mechanisms. In Part II of my analysis, I will identify the first collaborative scientific sensemaking discussion of each tutorial group and discuss the processes by which the groups get into such a discussion.

DATA ANALYSIS, PART II – WHEN, HOW, AND WHY DO TUTORIAL GROUPS START COLLABORATIVELY SENSEMAKING?

In Part I of my analysis, I found behavioral transitions amongst all three groups that marked their first discussion in tutorial, and discussed what led to those transitions. In Part II, I follow each group's subsequent discussions to look for evidence of collaborative sensemaking about physical phenomena, and identify the dynamics by which each group got into their first collaborative sensemaking discussion. As in Part I, I will provide instances of all three groups' use of distancing mechanisms in ways that help make space for the group to collaboratively sensemake. I find that once again there is variability amongst the groups in their sensemaking discussions, both in when they have these discussions and why.

The Bluebirds' 1st collaborative sensemaking episode

In Part I, I showed how the Bluebirds went from *reading what they wrote* to *saying what they think.* In analyzing their subsequent discussions, I find that the Bluebirds continue to say what they think. By their fourth discussion of the first tutorial, they show evidence that they understand their activity to include making sense of physical mechanisms. Having just made motion graphs by walking slowly away, resulting in a straight line of positive slope, the Bluebirds are asked to draw and discuss their predictions for a faster walking speed. This prompts a discussion in which they sensemake about the connection between their physical motion and the features of a graph of that motion, as I will describe in what follows.

CARMELLE	Darn it! Why am I not doing this dotted line thing?
BREE	It'd just be like a steeper slope (gestures with pen)
AMANDA	Right, okay.
DEIRDRE	Steeper slope, that's what- okay.
AMANDA	And not starting at the origin
DEIRDRE	Yeah a little bit higher
AMANDA	Yeah
DEIRDRE	(reading) and then, same thing. (gestures)
CARMELLE	But you know what...(they look at her) Okay. Okay. Okay right cause the steeper slope would represent
AMANDA	(over S3) Going faster
DEIRDRE	(over S3) A shorter
CARMELLE	A farther distance in shorter time (S1 and S2 finish her sentence with her) Okay
AMANDA	Right.

CARMELLE Okay. (nods)

Through this discussion, the Bluebirds collaboratively decide what the graph would look like, and why it would look like that. In doing so they are making sense of the motion graphs and how they were different from last time. They conclude that the steepness of the slope was greater, and they also remind each other not to start at the origin, a lesson learned in a previous discussion.

Reflecting On The Bluebirds' Early Sensemaking Dynamics—The Bluebirds have found a way to balance the processes of introducing ideas and evaluating them. They are not afraid in this moment to put their idea out there, in suggesting that the steepness of the slope is greater and the intercept is higher. They are also evaluating the ideas that are being thrown out there, either by agreeing with them, elaborating on them, or challenging them. Carmelle was about to push back against the steepness idea, "But you know what…" but then she apparently figures out why the steepness of the slope should increase in terms of the physics—"the steeper slope would represent…a farther distance in shorter time. Okay." In this way, the Bluebirds are softening their stances in ways that manage the epistemological and affective dynamics simultaneously. By making repairs of understanding and mitigating the affective risk of making those repairs, the Bluebirds have constructed a safe space to sensemake.

The Bluebirds are unique out of the three groups I am analyzing here in that they seem to make steady progress in coming to an understanding of their activity that allows for scientific sensemaking. Up until their first sensemaking discussion, the other two groups are showing more signs of anti-alignment with the goals of curriculum than alignment, through their dismissive approach. In both the Sparrows and the Ospreys it is the small act of an individual that seems to spark this dramatic change in the group's progress. First I will detail this process for the Sparrows, for whom a teacher's assistant steps in and helps the group right its course. Then I will tell how, for the Ospreys, it was a new student who was able to alter the dynamics of affective engagement enough for the group to create a space where they can sensemake by relying on their own ideas.

The Sparrows' 1st collaborative sensemaking discussion

In Part I, I showed how the Sparrows were dismissive of the first tutorial question. This dismissive approach continued for the Sparrows' subsequent discussions, until later in Tutorial 1 when a TA overhears them dismissing a good question. The TA uses this as an opportunity to get the Sparrows sensemaking, which he makes room for by incrementally adding epistemic distancing into his questioning pattern until the students started coming up with ideas. Then, he uses this sensemaking discussion as an opportunity to make repairs to the Sparrows' understanding of what it is they are supposed to be doing in tutorial. Once the TA leaves, they go right back to collaboratively sensemaking on their own. I will describe the TA's intervention as well as the Sparrows' discussion after the TA leaves.

The second question of the first tutorial asks them to walk slowly and steadily away from a motion detector while the computer displays a graph of the motion on the screen in real time. Once they stop moving, the graph stays on the screen and the students can orient to with their talk and action. Alan is the walker for this experiment. He walks slowly and steadily backward, while holding up a notebook to make a better target for the motion detector (as suggested by the TAs earlier). While he is returning to the table, he notices two "jumps" in the graph, but starts to dismiss them.

ALAN:	Wh- what are those two jumps?
DARIA:	I(h)- don't know.
ALAN:	Whatever.
CHRISSIE:	Okay,
DARIA:	*(trailing off)* You wanna try it again?
CHRISSIE:	*(reading out loud and trailing off)* Sketch the result...

Just when it seems that the group is on course to ignore these 'jumps' in the graph, TA Joey steps in to use it as an opportunity to engage them in sensemaking about the graph. He enters the conversation by re-posing Alan's question: "So wait a minute, that's a- that's a good question. What are those two jumps?"

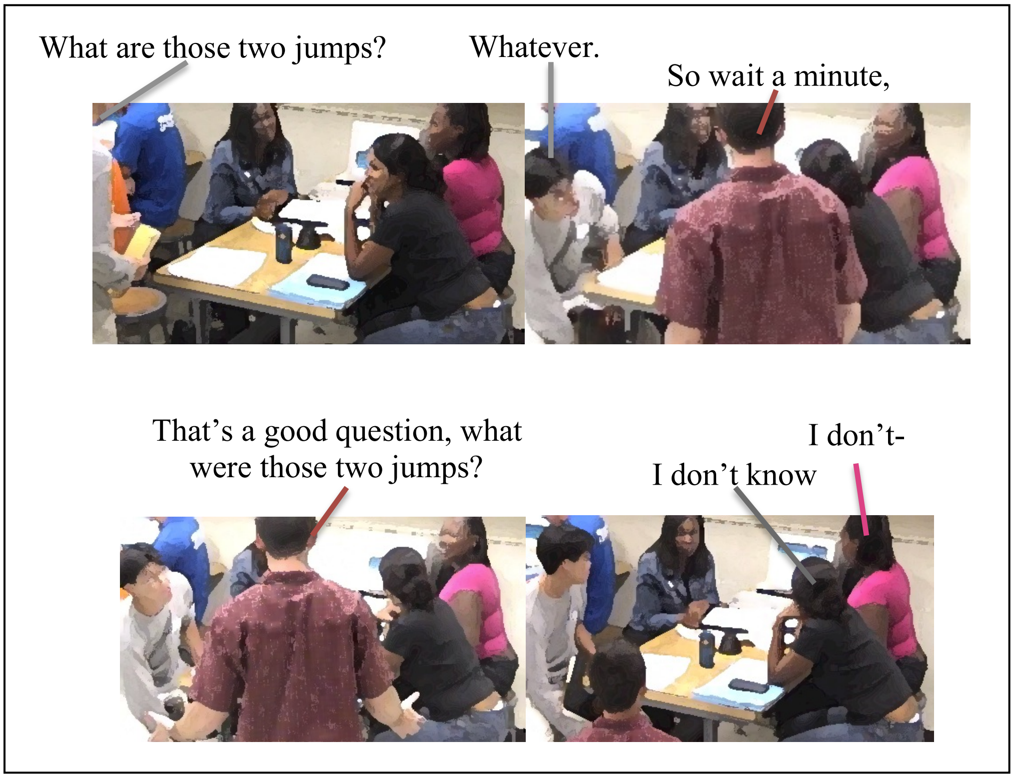

Figure 4.7—The TA overhears the group dismissing a good question joins in to help the Sparrows make sense of the graphs

When nobody responds, TA Joey kneels down and asks the question again, but with some epistemic distancing:

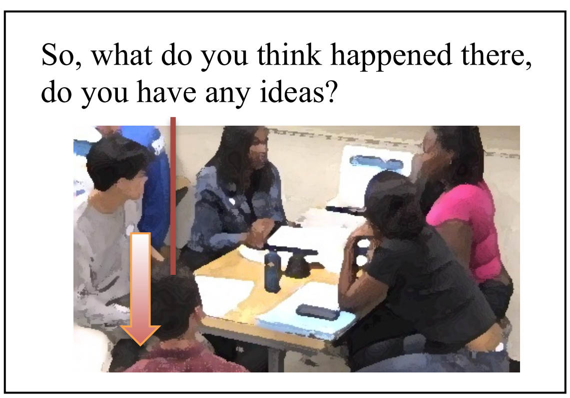

Figure 4.8—TA Joey introduces more epistemic distance to the question, when he kneels down and asks about what they *think* happened there.

TA Joey introduces epistemic distance to his question in a way that helps the Sparrows feel comfortable sharing their ideas. He then engages them in a sensemaking discussion about what might be causing the jumps in the graph in which the students offer competing suggestions, such as an unsteady walking pace and an inadvertent movement of the book they were using as target for the motion detector. Chrissie suggests that they do another trial. At this point TA Joey comments on this sensemaking discussion in order to make an explicit repair to the Sparrows' understanding of what it is they should be doing tutorial.

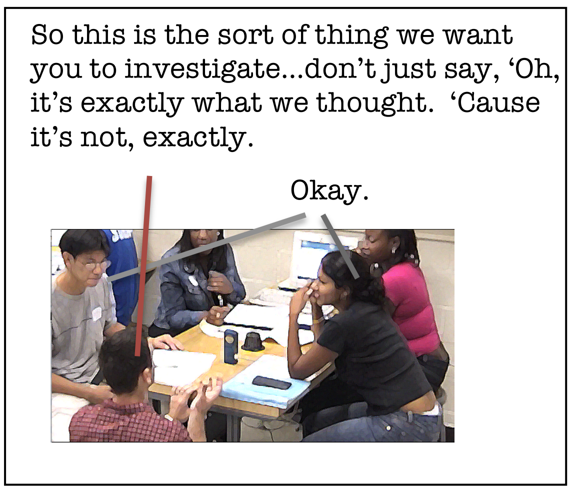

Figure 4.9—TA Joey uses this sensemaking discussion as an opportunity to repair the Sparrows' understanding of what they should be doing in tutorial.

After TA Joey leaves, they continue their sensemaking about the causes of the jumps in the graph. They follow Chrissie's suggestion and do another trial, which results in a straight line with no jumps in it. They celebrate this with smiles and laughter, saying "Okay it worked out." But before moving on to the next question they go back to making sense of the causes of the jumps in the original graph:

DARIA:	D'you wanna try again?
ALAN:	You wan/me t/a try it again?
CHRISSIE:	yeah
DARIA:	Yeah just /one/ try
BRANDI:	How /did ??/
DARIA:	Hold on,
CHRISSIE:	You gotta stand in front of it...ready?
ALAN:	Yep *(walks slowly away with book in hand)*
DARIA:	There you go:::::
CHRISSIE:	Ah::::, okay,
BRANDI & DARIA:	(laughing)
DARIA:	Okay it worked out.
CHRISSIE:	So maybe you weren't walkin' at a steady pace at one point
ALAN:	Probably, I probably like moved the book or something like that
DARIA:	Did you? Yeah maybe
ALAN:	Yeah.
DARIA:	Wait did you do something different the first time?
ALAN:	No.
DARIA:	/While you were/ walking back?
ALAN:	I was- I- I probly...I donno either=
BRANDI:	[Sometimes you do things subconsciously
ALAN:	[=moved the book down or, you know, whatever yeah
CHRISSIE:	So where do you, you write that where? Oh, for B.

This discussion provides evidence that the TA's intervention has had a lasting effect on the Sparrows' understanding of their activity.[11] In this discussion, the Sparrows illustrate that they have built a shared understanding that the "jumps" in the graph are entities that they should point out and try to make sense of. TA Joey's moves served to not only to refine not the Sparrows' shared conceptual

[11] As I will demonstrate in Chapter 5, the Sparrows continue to sensemaking about their motion graphs, so much so that they sensemake about bumps in their graphs even when the tutorial worksheet tells them to just "smooth out the bumps."

understandings, but also their epistemological understanding of what it is they are supposed to be doing in tutorial. As I will discuss in the next section the Ospreys also build a shared understanding that they should be making sense of their motion graphs, after a new member of the group challenges the norms of the group with a simple question.

The Ospreys' 1st collaborative sensemaking discussion

In Part I, I showed that the Ospreys' first discussion contained some of the precursors of collaborative sensemaking. For instance, Cathy and Devin each described some of the mechanisms by which talking about your mistakes could help them learn. But Adam's comment, "It's been proven that you learn from your mistakes" seemed to shut down the conversation. After that point, the Ospreys' discussions contained little evidence of collaborative sensemaking for the rest of the first tutorial.

It is not until the beginning of the second tutorial when the group goes into a discussion in which they are collaboratively making sense of a physical phenomenon. Note that in this tutorial the group membership has shifted. Seating arrangements in tutorial are generally self-organized, people may sit wherever they wish unless otherwise noted (which the TA *will* otherwise note in the 3rd tutorial, telling them to keep the same groups). But even with this open policy, students tend to return to the same groups—to the same seats, in fact. Devin, for instance stays in the same seat for most of the semester. But of the three groups in my study, the Ospreys are the only group to not have its original members by the end of the semester. In Tutorial 2, Cathy is gone and a new member Britte is present.

As in the first tutorial, the second tutorial asks the students to make motion graphs and to compare their predictions against the resulting graph. In Tutorial 2, they are making graphs of their velocity versus time. The Ospreys start out the tutorial drawing their predictions of a velocity vs. time graph for someone walking slowly away from the detector. They are focused silently on their worksheets for several minutes, before Brad suggests they get to the experiment:

BRAD: Should we let it rip?
BRITTE: Are we um, allowed to discuss now?
DEVIN: Yes.
BRITTE: MMmkay.../let's see/...

Brad suggests they get started with the experiment. Britte, who is new to the group, solicits a repair of understanding of what "it" is they are supposed to do by asking, "Are we, um allowed to discuss now?" Devin answers in the affirmative, and this prompts them to show each other their graphs and to discuss their predictions:

BRAD: *(holds his tutorial booklet up, silently, for others to see.)*
DEVIN: /Wait/
BRITTE: *(looks at Devin's worksheet, holds hers up)* I have the opposite of you aheh...Why?
DEVIN: *(puts her tutorial booklet in middle of table, then looks at Brad's)* So, /it's my thinking was/ the um, (::) velocity's gonna increase *(hand gestures)* AS it's going down?
ADAM: But since it's a constant acceleration wouldn't it be a *(gestures)*
BRAD: Well, velocity's gonna increase *(gestures)* because, it's just FALLing *(gestures)*...slower so things...increase /steadily in speed/ when they fall. And they fall at constant acceleration.
ADAM: Constant acceleration but should be velocity?
BRAD: /yeah it's curved/
ADAM: the curve is supposed to /change/
DEVIN: /Absolutely/. Right right.

Reflecting On The Ospreys' Sensemaking Dynamics—This discussion contains evidence of the Ospreys' collaborative scientific sensemaking. They notice inconsistencies in their graphs and seek to resolve them by reasoning about how the physical motions connect with features of the graph. There is also evidence that this sensemaking is facilitated in part through epistemic distancing. Britte was challenging Brad's move by suggesting that they discuss their predictions, but she did so with considerable hedging. This enabled her move to influence the dynamics of the group towards alignment with the tutorial goal of collaborative sensemaking.

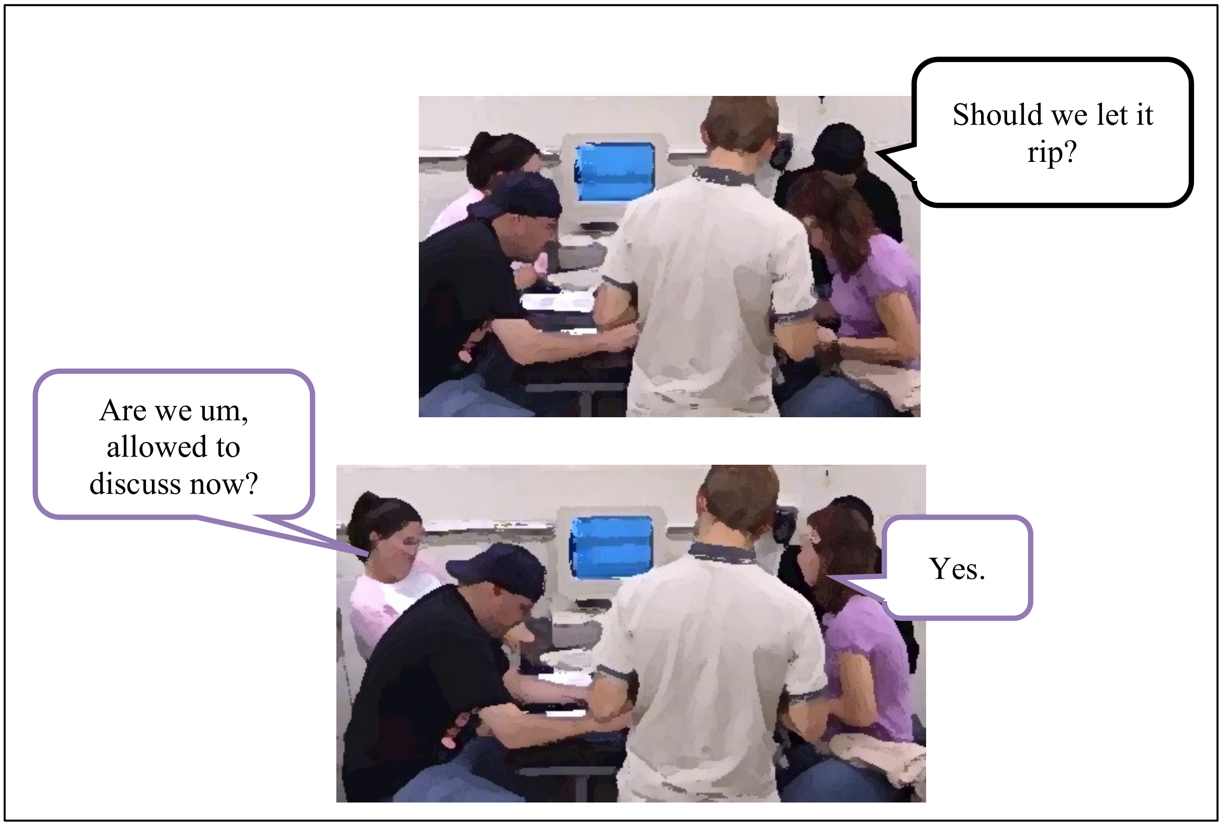

Figure 4.10—Brad bids to start the experiment, while Britte suggests that they discuss their predictions, with considerable hedging.

Once they have this first sensemaking discussion, the Ospreys continue to have them throughout the rest of the semester, although these discussions are not as frequent as the other two groups. I will discuss these longer-term dynamics in Chapter 5.

Summary of Part II—Reflections on the groups' sensemaking dynamics

In Part II, I explored the dynamics of collaborative scientific sensemaking within the groups throughout the first tutorial and, in the case of the Ospreys, the second tutorial. I found that the Bluebirds made steady progress towards making a safe space for sensemaking, in part by using epistemically distancing in ways that help maintain a safe space to introduce their own ideas and to evaluating them. I also showed that although the Sparrows were heading into anti-alignment with the goals of the tutorial, a TA stepped in at the right time and helped them right their ship. And finally, the Ospreys got there when a new student phrased a simple question in a interesting way, "Are we um, allowed to discuss` now?"

CHAPTER SUMMARY AND DISCUSSION

In this chapter, I showed how three tutorial groups were able to able to build a shared understanding of the nature of their activity. I first laid out the theoretical foundation for understanding how tutorial groups can maintain a safe space to sensemake by managing the epistemic distance between them and their statements. In the rest of the chapter I analyzed how three tutorial groups managed these dynamics within their first few discussions of the semester.

In Part I, I analyzed each group's very first discussion of the semester, finding that all the groups got into the discussion by following the tutorial instructions. However, there was evidence of variation across groups in how they understood those instructions, based on how they approached the discussion. Part of this variation can be explained by differences in how each group managed the epistemological and affective dynamics of their discussion. Through the use of turn-taking and epistemic distancing, the Bluebirds were able to construct the beginnings of a safe space to sensemake as they shifted from *reading what they wrote* to *saying what they think*. The other groups either distanced themselves too much (the Sparrows) or too little (the Ospreys) to share much of their thinking in the first discussion.

In Part II, I identified and analyzed each group's first discussion that showed significant evidence that the students were collaboratively sensemaking about physical phenomena. There was variability in the timing of when in the tutorial this discussion occurred for each group, and how they got into the discussion. In the case of the Bluebirds, they progressed steadily in their sensemaking over the first few discussions. For the Sparrows and Ospreys, the groups were showing few signs of sensemaking, until an outsider from the group challenged them to engage in the tutorial in a new way. The Sparrows started sensemaking together after a nearby TA overheard a good question and used as an opportunity to engage the group in a discussion, and to repair their understanding of what they are supposed to be doing in tutorial. The Ospreys started sensemaking when a new student asked the group, "Are we um, allowed to discuss now?"

These findings contribute to research on how students in tutorial come to understand the epistemological nature of their activity in tutorial, i.e., their epistemological framing (Bing & Redish, 2009; Elby & Hammer, 2010; Hutchison & Hammer, 2010; E. Redish, 2004; Scherr & Hammer, 2009). The analysis of these three tutorial groups has shed light on some of the dynamics by which tutorial groups build these shared ways of framing their activity. In Chapter 5, I will contribute to this research further, by following the groups through the rest of the semester to show how these shared understandings evolve over longer timescales.

Chapter 5: Long-Term Dynamics of Tutorial Groups' Collaborative Sensemaking

INTRODUCTION

In Chapter 4 my primary analytic focus was on the initial interactions by which the behavioral clusters and sensemaking discussions emerged within the tutorial groups. To study this, I chose to look at the first discussion of each group in fine-grained detail. How does this connect to their longer-term dynamics? Research on small groups (Arrow et al., 2000; Bettenhausen, 1991; Bettenhausen & Murnighan, 1985) has emphasized that the earliest phases of group formation are precisely when the groups are establishing the norms that will supervene on and in ways even constrain their future progress. And so by gaining an understanding of how the tutorial groups first manage to construct some shared space to sensemake, we gain insight into the tools by which the groups maintain the stability of these shared understandings throughout the rest of the semester. But it would be unwise to simply assume that the tools the groups use to initially construct the shared space are important for the longer-term dynamics of the group's interaction. And so, it is important to begin to undertake the task of characterizing and accounting for the dynamics on longer time scales. My conjecture is that these tools from the beginning will be used throughout, but I am not assuming that these are the only tools likely to be relevant.

The analyses in Chapter 4 suggest that small things can make differences in the group's sensemaking trajectories toward sensemaking. It could be an instructor overhearing a group as they dismiss an opportunity to sensemake (in the case of the Sparrows), or it could be a new student who is unsure of the norms of the group (in the case of the Ospreys). These examples serve us as existence proofs of the facts that (1) the tutorial instructors can make enormous positive influences on the sensemaking practices of the groups, and (2) that the norms of the group are still subject to perturbations from individual members of the group.

It is important to continue the story of these groups to determine that these differences in practice were lasting differences. With that in mind, I promised in Chapter 4 that I would report on some of these longer-term dynamics of the groups' sensemaking practices. What happens with the Sparrows is quite interesting: In following TA Joey's advice sensemaking about graphs, the Sparrows have a lengthy discussion only find out they are sensemaking when they are not supposed to. I will report on these dynamics in this chapter, drawing implications for instruction and for curriculum development.

First, I start with piecing together a story out of relevant moments from the Sparrows Tutorial 1 after TA Joey stepped in and helped them start collaboratively sensemaking about anomalies in the graph. I show that this understanding is one that the Sparrows take away, and stably so. It is robust enough to withstand several instances of mixed messages with respect to whether they should discuss anomalies in the graph.

Then, I will present a relevant moment from later on in the tutorial for each group. I will compare how each group approaches the same tutorial problem—drawing the force diagram for a roller-coaster cart that is upside down as it goes around a big loop in the track. I will use this example as a touchstone for discussing each group's longer-term dynamics.

<u>THE SPARROWS – "SMOOTH OUT THE BUMPS"</u>

As reported in Chapter 4, the Sparrows at first are dismissive of the epistemological goals of the tutorial, until a tutorial instructor steps in to help them engage in some scientific sensemaking. He encourages them to help each other make sense of things such as unexpected bumps in the graph. He also "goes meta" to say *this discussion* is the sort of thing we want you to be doing. This interaction proves to be quite a formative moment for the Sparrow's shared understanding of the nature of how to engage with the tutorials. However, that shared understanding is not set in stone, and is vulnerable to perturbations (as the Ospreys helped us see with a new member challenging their norms with a simple question). And there are many mixed messages sent to these students in tutorial, some of which will threaten their understanding of tutorials that includes collaborative scientific sensemaking. And some of these threats will come from the tutorials themselves.

The Sparrows should be considered a successful tutorial group. But it is illuminating to follow their bumpy path of sharing an understanding of what the tutorials are all about, in part because it includes some surprising twists and turns. In Chapter 4, I reported on the interactions during the Sparrows' first discussions of their first tutorial. In what follows, I will expand upon the analysis provided in Chapter 4 of the Sparrows' first sensemaking discussion. I use this example to illustrate the stability of the Sparrows' understanding that they should be collaboratively making sense of unexpected features of their motion graphs.

TA Joey to the rescue

When TA Joey stepped into the conversation, he was soliciting ideas for what might answer Alan's question about two unexpected bumps in the motion graph he just made: "What are those two jumps?" As TA Joey increases epistemic distance for them get their ideas out there, "going from "what happened there?" to "what do you think happened there?" to "do you have any idea?" they finally start to propose some ideas. When TA Joey heard Daria's suggestions that the motion detector is "just getting started up or something," he revoiced it in such a way that gave Chrissie the idea to retest it, which they did. TA Joey had asked a clarifying question, "It was getting started up, so like if we did it again (rolling hand motion), like now it's warmed up almost (revoicing) like…" and Chrissie suggested, "I think we should do a second trial." TA Joey suggests to them that "this is the sort of thing we want you to investigate," and lets them do so. And when they do that second trial, the bumps are gone, and they have a positive affective response where they all smile and laugh and generally express happiness with the result:

Figure 5.1—The Sparrows are happy after they do another trial and the "jumps" in the graph do not show up this time.

DARIA:	There you go:::::
CHRISSIE:	A::::h::::, okay,
	DARIA & BRANDI laughing
DARIA:	Okay it worked out.

But they do not simply consider the matter settled. They continue to try to make sense of what the bumps were on their previous graph. They generated ideas about their meaning, from Alan walking unsteadily or moving the book:

CHRISSIE:	So maybe you weren't walkin' at a steady pace [at one point
ALAN:	Probably I probly like moved the book or something like that
DARIA:	Did you? Yeah maybe
ALAN:	Yeah.
DARIA:	Wait did you do something different the first time?
ALAN:	No.
DARIA:	/While you were/ walking back?
ALAN:	I was- I- I probly...I donno either=
BRANDI:	[Sometimes you do things subconsciously
ALAN:	[=moved the book down or, you know, whatever yeah

When Daria asked if he had done something differently the first time, Alan was hesitant. Brandi even made sense of this lack of perception of having done things differently, by suggesting that it was something he did subconsciously.

In short, the Sparrows were about to dismiss a good opportunity to sensemake when TA Joey intervened. He engaged them in a sensemaking discussion, and used that as an opportunity to repair the Sparrows' understanding of what it is they should be doing in tutorial. There are signs that this understanding is quite stable over longer time periods, as I will describe in the next section. In what follows, I provide an example of this stability using an example showing how the Sparrows keep sensemaking about the bumps in the graph despite the tutorial instructions telling them to "smooth out the bumps."

The Sparrows' 1st transition to sensemaking: Smoothing out the bumps

In particular, Sparrows are making sense of the fact that there are unexpected bumps in their graph of velocity vs. time, although these are apparently of a different nature than the previous "jumps" considering that they come up with an different explanation for it. Alan attributes the bumps to changes in speed as he is taking each step.

DARIA:	With each step you take? or do you think like because...
ALAN:	I think it's each step
DARIA:	it's like : not exactly the same speed you're going
ALAN:	Because, when I'm taking a step, right, you leave one foot, and then not=
BRANDI:	
ALAN:	=exactly traveling anywhere when you're moving your foot, right?
ALAN:	You know when you think about walking, you- it's like one : foot then you move : one foot then you move (gestures walking with fingers)
CHRISSIE:	Like when you move each foot /you/
ALAN:	Yeah, so it /keeps/
DARIA:	Oh it says here 'when sketching the results.../?/
ALAN:	Yeah, smooth out the bumps, when you're...
DARIA:	Okay.
ALAN:	Whatever.
CHRISSIE:	What does it say?
ALAN & BRANDI:	It says 'smooth out the bumps'
DARIA:	I feel like we're missing /a piece/ (laughing)
CHRISSIE:	Ohh
ALAN:	Whatever.
DARIA:	Okay, skhehehe

The Sparrows were in the middle of collaboratively sensemaking about the graph and how it connects to their motion, yet when they look to the tutorial for guidance it tells them, “When sketching the result of this and other velocity graphs, smooth out the ‘bumps’ that result from your stepping.” Daria chuckles and expresses embarrassment since she was questioning whether the bumps were in fact connected with the stepping. Alan, on the other hand, expresses frustration. Overall, this kills the discussion, as the group goes back to individually completing the worksheets.

When TA Rosslyn comes over to check in with them, however, she asks them to share what they thought about the bumps in the graph. Note that this is another instance of a TA taking responsiveness into their own hands in ways that are in alignment with the tutorial, due to the contingent dynamics of the Sparrow’s progression through the tutorial. They responded confidently, “Steps”:

TA ROSSLYN:	(walks up to table) So what's going on over here?
DARIA:	(looks up) Oh he stopped right there that's why <heheh>
ALAN:	Yeah I came really close and then pulled the...
TA ROSSLYN:	That's why it goes kind of funky there? Well that's sort of reasonable.
ALAN:	Yep.
TA ROSSLYN:	So...are we trying to show a constant speed here is that?
ALAN:	Right. Yeah.
TA ROSSLYN:	Okay so, what do you think is accounting for those slight bumps in it.
ALAN:	Ahhhhh::: my steps
CHRISSIE:	His..steps.
TA ROSSLYN:	Ohkay so,
ALAN:	Cause'm not exactly moving when I take a s- well the speeds always modulating every time I ehh (trails off)
TA ROSSLYN:	Right. OKay, great! Yeah. And what does it mean that it's below the axis?
ALAN, CHRISSIE & DARIA:	because he is moving towards the detector.
TA ROSSLYN:	Okay. Okay! (nods & walks away)

TA Rosslyn walks up and asks them what seems like a general question, “What’s going on over here.” Daria looks up and responds to her as if she was asking about the bump in the graph, responding, “Oh, he stopped right there, that’s why <heheh>” and afterward Alan explains how corresponds with something he did while walking. TA Rosslyn then evaluates that explanation positively, as “sort of reasonable.”

She then asks about they account for the “slight bumps.” This is something that the Sparrows have has thought through already, although the tutorial had shut down their discussion. But they have reasoned through it and thankfully TA Rosslyn asked about it. So it happens that they have a quick, sensible answer, which they deliver with confidence: “His…steps.” Alan fills in the explanation that his speed is subject to small “modulations” each time is takes a step. She praises this answer: “Okay, great!”

TA Rosslyn has responded by their sensemaking by going with it, and asking them to make sense of all the “funky” features of the graph, even some features that the tutorial worksheet instructs them to ignore. This responsiveness on the part of the TA is in service of a greater alignment with the epistemological goals of the tutorial. And, since the Sparrows have already thought through this, they have a great answer already cued up. The Sparrows are therefore encouraged in their trajectory towards collaboratively sensemaking about the physics.

Reflections On “Smoothing Out The Bumps”—TA Joey’s intervention helped the Sparrows get back on course with respect to collaboratively making sense of the graphs, only to get feedback from the tutorial worksheet implies to them otherwise. The tutorial shuts down their sensemaking discussion. But it is underdetermined at this point whether they take that to be repairing their understanding to say that you should not make sense of the graphs after all, or just, “you should not make sense of these bumps”. Either interpretation would be against the grain of the epistemological goals of the tutorial. Luckily the TA Rosslyn provided the necessary responsiveness and asked them to make sense of those bumps anyway.

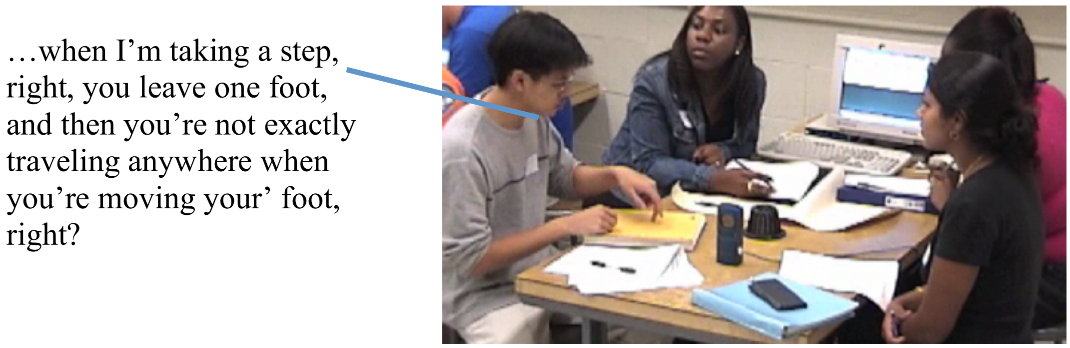

Figure 5.2—Alan and the Sparrows are collaboratively sensemaking about the bumps in the graph.

In the end they received positive feedback for their sensemaking, and that is what counts in the end for the Sparrows, it seems. They proceed to have strong scientific sensemaking discussions in throughout the semester. They do so even though there are more mixed messages sent their way in Tutorial 2, when TA Joey has to tell them to not make sense of parts of the graph as technical glitches. Their continued sensemaking, even when encountering more “bumps” in the form of mixed messages, is a sign of stability in their understanding that they should be sensemaking together.

PORTRAIT OF THE GROUPS IN TUTORIAL 9 – A CART ON THE LOOP-THE-LOOP

In what follows I will present the three groups' approaches to the same part of the same tutorial, late in the semester. I will describe each group's approach in turn, using it as a touchstone to discuss their dynamics more generally. First, the Bluebirds set the standard for an understanding of the tutorial that includes collaboratively sensemaking about physics. They approach the tutorial as if they expect to collaboratively sensemake, as I will detail in what follows.

Some Thoughts On Longer-Term Dynamics—So far, I have reported in this chapter on how the Sparrows encounter bumps along their way in the process of building a shared understanding of what they are doing in tutorial. This serves as an illustrative example of the fact that even after the groups build a norm where they use the discussions to collaboratively sensemake, there are challenges to that norm arising inevitably as they make their way through the tutorials. But how does each group maintain this dynamic beyond the first few tutorials, and throughout the semester? Do the green modes survive to the end? How about the collaborative sensemaking? While I can provide answers to some of these questions, a more detailed analysis of the long-term dynamics will have to be left for future work. In what follows, I will briefly characterize my sense of each group's long-term dynamics of their shared understandings of what they are doing in the tutorial. I start off with an illustrative example from a single question that all three groups approach in interestingly different ways as a way of presenting a snapshot of all three groups near the end of the semester, summarizing any lessons to be learned. First I use the example of the Bluebirds to discuss their long-term dynamics and compare it, in turn, to the Ospreys and the Sparrows.

The Bluebirds – Still sensemaking, after all these tutorials

The Bluebirds have been collaboratively sensemaking during their discussions ever since Tutorial 1, without much nudging from the tutorial instructors. In fact, after the students leave the room at the end of the first tutorial, the TA's have an informal discussion of how it went. They noted how the Bluebirds were great, and TA Joey mentions that he heard the great discussion they were having and just "let them go." This approach is apparently successful, as the Bluebirds consistently do good work throughout the rest of the semester.

In Chapter 1 I briefly highlighted the Bluebirds' approach to a problem in Tutorial 9 as exemplary of the Bluebirds' resolving a discrepancy by discussing their sense of the physical mechanism between the cart and the track. This episode is indicate of the Bluebirds' general approach to the tutorials, which seems to be a reliable oscillation between working on the problems individually, and then going into a sensemaking discussion when there are disagreements. I will present that episode briefly here, then compare it with the Ospreys and the Sparrows.

In tutorial 9, the students are walked through the calculation of the minimum release height needed for a roller coaster to get around a "loop-the-loop," a large loop in the track where the cart is, for a time, upside down. To calculate the minimum release height, they need to calculate the minimum velocity needed to reach the top of the loop with still enough kinetic energy left at that point to get all the way around the loop without falling off the track. In the service of finding this minimum velocity, the students are instructed to draw a force diagram at the bottom of the loop, and then again at the top of the loop. The Bluebirds go from doing their force diagrams individually on the worksheet to discussing their ideas about them. The abrupt start "well there's gravity" implies an expectation that they would discuss their force diagrams:

BREE:	(looking at AMANDA, then down at her worksheet) Okay. (5 second pause)
AMANDA:	Ohmygod.
BREE:	(looks up, then back down) Alright...(5 second pause)...There's mmm...
DEIRDRE:	Well there's gravity
BREE:	Gravity's going down...
CARMELLE:	I mean you have the force of the track pressing it down
BREE:	(over DARIA) the force of the track pushing down
DEIRDRE:	But wouldn't it-
AMANDA:	going down
DEIRDRE:	Would it be going up or would it be going like (drawing) like that?
BREE:	What?
DEIRDRE:	The force of the track

All the students seem comfortable with identifying the force of the track, as well as the force of gravity, as the relevant force on the cart to consider. However, not all of them put the normal force pointing down, towards the center of the loop[12]. Deirdre makes a move to repair understanding of the direction of the normal force, but she restarts and phrases it as a solicitation of repairing her own understanding rather than a move to repair theirs. This is helps everyone save face as they come to agreement on the direction of the normal force, as they do as the discussion continues.

BREE	Nah, it's going (gestures) down
CARMELLE	Cause its pressing down (gestures- see Fig 3) on it, it's at- it's at the top part it that top part of is is what's pushing down
BREE	(in unison with CARMELLE) pushing down cause that's

[12] These observations hold for the Sparrows and Ospreys as well.

	what's holding it in from like being shot like (gestures) way out
DEIRDRE	So there's a
BREE	Just pretend like if you, if this was not like going up and down, just like (gestures) you know, going around=
DEIRDRE	Okay
BREE	=in circular motion, it has to be pressing in=
DEIRDRE	Oh, okay
BREE	=to keep it from like shooting out (points away) (the group goes back to their worksheets)
AMANDA	(pause) So what- what force is that, normal /force/?
BREE	Normal.
CARMELLE	Mmmhm

So both Carmelle and Bree provide justifications of the downward direction based on their intuitive sense of the mechanism of interaction between the cart and the track. Carmelle explains it in terms of the organization of the relevant entities: the track is above the track and so must be pushing it down. Bree explains it in terms of competing inward and outward influences of some sort: the force of the track is what keeps the cart from "being shot like (gestures) way out". After this, Deirdre concedes the point, and they go on to attach to it the physics term "Normal" and they go back to individually proceeding through the worksheet.

This is a nice example of collaborative scientific sensemaking. The Bluebirds are collaboratively figuring out together the details of the physical mechanism. They are doing so by introducing their ideas and leaving them open to evaluation, and working toward consensus. While space limitations prevent me from showing more of their interactions here, my sense is that this example is quite indicative of the Bluebirds' general approach to tutorial.

The Ospreys – "What direction is the weight?"

The Ospreys spend the first 15 minutes or so of Tutorial 9 trying to figure out the answer to first tutorial question: *Can you solve for the velocity of a block as it slides down a curved track?* They had been discussing which variables they knew and which equations linked those. In the service of that, they pulled out their notebook, because they did not remember the kinematic equations. When they had the book open, they had a lengthy discussion with TA Ashton about calculus, which the TA concludes by saying, "There isn't enough info, but you could do it. IF I gave you enough info." Strangely though, they proceed to the next part of the tutorial based on the kinematic equation they were just given, instead of the conservation of energy equation they are "supposed to" use. It is strange that the TA just told them they do not have enough information to solve it that way, and yet they proceed to use the same equation:

DEVIN: (starts reading part II out loud)
DEVIN: Can we use the same equation then?
CENA: Yeah, /or the initial/.

By using the kinematic equations from their notebooks, they end up getting the right answer, but by the wrong means. This perplexes TA Bob when he checks in, and he uses it as an opportunity to explain a subtlety about gravity that makes them right but in a way that they could not have known about (particularly since this is an algebra based course).

Filling In The Force Diagrams For Points A And B On The Track—By the time they are doing the force diagram, their lecture notes are still out on the table from looking up the kinematic equations part I, and now they use them to look up what the professor said about this particular loop-the-loop problem. Their approach to this part centers on attending to what is written in their notes, rather than on collaboratively sensemaking about the physics. As Devin is about to do her force diagram, Britte lets her know it should be in her notes:

BRITTE:	We did this in class, but...I don't think I wrote it down right. (closes notebook and puts it aside)
CENA:	/What was he saying times something (gestures)
BRITTE:	/what now/
	I remember him writing /that too/ /??/
BRITTE:	(looks at DEVIN's paper) Are you sure that it's just N and mg?

They are not collaboratively sensemaking about the cart during this part of the question, unlike the other two groups. The transcript does not capture the long silences during which the group searched for the answer in their lecture notes. Britte solicits repair of her understanding of the normal force, but solely on the basis that it is different than what she had written down in her notebook. The Ospreys get different answers for the normal force, and so then they backtrack to find where their equations diverged. They do no at any point collaboratively make sense of the physics of the track and the cart. At this point TA Bob comes by for a check in.

TA Bob Checks In—TA Bob notices that there is something strange going on with their force diagrams at the top of the loop-the-loop. It's hard to say for sure, but most likely the group put the normal force pointing upwards. The TA designs his questioning in a way that leads them to the correct answer by relying on their intuitions about the normal force more productively. He starts this by having them construct the diagram at the bottom of the loop. When they get that right, TA Bob presents a novel scenario: the force diagram at the *side* of the loop. They get that right, since they remember that the normal force is always perpendicular to the surface. Then TA Bob asks about the diagram at the top. Devin catches on that the normal force is the other way around from what they have drawn there. But then something unexpected happens. TA Bob asks them what direction is the weight, seemingly using it as another scaffold for them to get something right that they can rely on. But the Ospreys are confused by this question:

TA BOB: SO, what do you think is going to be at the top?
DEVIN: Is it the other way around?
BRITTE: Yeah. /I put/
TA BOB: Well, what direction is the weight?
DEVIN: Is the w- ...'way'?
TA BOB: Tha- M G.
DEVIN: That's what I'm confused on, isn't that-

Then Britte apparently draws the weight vector going *up* on her diagram:

BRITTE: Would it be...that way?
TA BOB: What now?
BRITTE: /Should be doing/ that? (points with pen, seems to be pointing up relative to the loop)
TA BOB: Well what direction is weight.
DEVIN: M G always has to be (gestures downward)
TA BOB: Right, M G always points towards the center of the Earth, right?
BRITTE: Ahuh
TA BOB: So it's going to be pointing down.
(They all make note on their worksheets)

The Ospreys are silent or a moment as they wrote that down that gravity points down. Cena then expresses confusion over how it applies to this context of being upside-down on the loop-the-loop:

CENA: Even if its...flipped over?

TA BOB: /alright/

DEVIN: Yeah, cause gravity's always gonna be pulling you down.

CENA: Yeah makes sense <hahah>

TA BOB: So what about the normal force, what direction is that going to point.

DEVIN: Same...direction?

TA BOB: Why.

DEVIN: Because it's the same here, here, like it's always going to pointing inward.

TA BOB: Always pointing away from the track (gestures up with thumb)

CENA: Mmhm

TA BOB: That's one way to say it cause if you're standing on a track, the normal force is pushing up on you----END OF TAPE

So, Which Direction Is The Weight?—Unfortunately the tape ends before they finished their conversation. Although there is evidence they are shifting their understanding of the force diagram at the top of the loop, we do not know for sure how stable that understanding is. It is particularly true in light of the Osprey's confusion over gravity, although ultimately Cena seems to "get" why it is down, chuckling and saying, "Makes sense." Her chuckle may be a face-saving act in light of being corrected, particularly on something that seems somewhat obvious in retrospect. It may belie a realization that she must not have been making sense up to that point. But that is not necessarily true, of course. It could be that she was sensemaking silently—and in fact I suspect there was likely some intuitive reasoning behind saying gravity is up at the top of the loop. But whatever was going on in Cena's head does not change the fact that the group was not collaboratively sensemaking.

So, in comparison with the other two groups, the Ospreys are not looking very collaborative nor do they appear to be taking much time to make sense of the physics.

While this is true comparatively to the other groups, this is not to say that the Ospreys are not doing *any* collaborative sensemaking. They had spent the first 15 minutes of tutorial 9 making sense of a part of the tutorial they were not supposed to spend so much time on, so they may have been playing "catch up" at this point in the tutorial by not collaborating too much. They were also pulled from their lecture notes away from making sense of the causal relations between the cart and the track. Rather, they are apparently just copying their notes from class into the tutorial notebook. The TA had discouraged them earlier from using their lecture notes, saying, "Aww you got your notebooks out? That's not coooool." The Ospreys decided to keep them out anyway, and the TA did not follow up. Now we see the detrimental effects of these decisions on their ability to create a space to collaboratively sensemake[13].

Brief Discussion Of The Ospreys' Longer-Term Dynamics—While there are not many signs of scientific sensemaking in this example, this is not to say the Ospreys' discussions are totally devoid of collaborative sensemaking at this point in the semester. In fact, in Tutorial 10 they have a pretty great discussion about why the astronauts feel weightless when in orbit. However, they go there much less

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[13] In Tutorial 10, when their notebooks are away, the Ospreys actually go into a nice collaborative discussion about why the astronauts experience "weightlessness". Notably, Devin starts the discussion with an ironic shift in footing, mockingly shifting register to say, "Ready to compare our answerssss…" This is quite like how the Bluebirds got into their first green mode discussion, as discussed in Chapter 4.

frequently than the Bluebirds, and do not sensemake as deeply when they do. Nor do they tend to sensemake as much as the Sparrows, as I will describe in what follows.

The Sparrows' approach to the loop-the-loop: "How do we relate the two forces?"

The Sparrows are sort of the "in-between" case out of these three groups both in their sensemaking about the loop-the-loop problem, and in their sensemaking throughout the semester. Generally speaking, they continue to have sensemaking discussions quite often throughout the semester, more so than the Ospreys. Still, they not as consistently aligned with the aims of the tutorial as the Bluebirds. In their discussion of the forces on the cart, the Sparrows do at least behave as if they are expecting to share their ideas about which forces are acting and in what direction. They are sensemaking, when it comes to the forces acting on the cart at the top of the loop-the-loop. First, they determine how many forces there are. Chrissie makes sure that friction should not count:

CHRISSIE:	(reading out loud) A greased block with mass...
DARIA	(reading out loud)
CHRISSIE	Lord God....
DARIA	Oh it goes like :: this
CHRISSIE	At point B?
DARIA	(reading out loud) Draw a free body diagram...point B...top
DARIA	Yeah /I assume/ just going down...weight
ALAN	Weight /?/ on the block and you have the weight, I mean, the normal of the track on the block
DARIA	/would be down/
ALAN	Ummm, what else do you have.
DARIA	/?/
CHRISSIE	Do you have any friction?
ALAN	No, no friction.
DARIA	No, because /it's greased./
CHRISSIE	It's what?
DARIA	It's /greased/?
CHRISSIE	Cause it's- it'd just be two right? Okay.
ALAN	Do you /know/ the tangential force?

CHRISSIE	Oh, please. Please. (nodding no)
DARIA	NO, because at that point,
ALAN	Yeahyahyahyah
BRANDI	So both forces are downward?
ALAN	(gives 1 nod and I think says Mhm but goes back to working.)

There are some elements of collaborative sensemaking here. First, with respect to the collaborative nature of their activity, notice that they are reading out loud as they proceed individually through their worksheets. While reading out loud may serve individualized purposes, it also serves the purposes of letting everyone else know where you are on the tutorial. This is a critical element of the group getting on the same page and keeping it that way, both figuratively and literally. This perhaps belies an overarching shared understanding encompassing both blue mode behaviors and green mode behaviors, wherein the completing the worksheet and having discussions are both part of serving the same overall learning goals. While Goffman talks about this "embedded" nature of our understandings of the physical and social world, particularly as navigated through shifts of footing (1974). Reading out loud is a shift of footing, as cued by a register shift in the voice and the unintelligibility of the sentences, which indicates that the listener should not to take the content as being from them. Through this practice, the Sparrows turn the individualized activity of completing the worksheet into one that is serving the broader purpose of working together through the tutorial.

And what they are cooperating about here involves some sensemaking about the cart as it interacts with the track. They go from completing the worksheet into having a discussion about the forces involved in such a seamless manner that it signals an expectation that they will discuss things at the relevant times. Which times seem relevant to the group can be evidence of their epistemological approach to tutorial. In this episode, we see that they move to a discussion to get on the same page with respect to the force diagrams. They each feel safe enough to give their ideas of which forces are involved, and which way they are pointing. So far, that is about the extent of it.

There is room for improvement when it comes to collaborative sensemaking here. Most notably, it seems Alan is positioned as a person who knows. One problem is it leads to Brandi being shrugged off when she seems to express some confusion about which way the forces are pointing. This could have been a productive discussion point, especially since in what follows we find the group flopping back and forth between saying that the forces are both downward, and also that they are canceling out.

Alan's positionality as "expert" or "leader" not only get them into conceptually murky waters here, but is problematic because while he comes across as knowing the answer, he is somewhat unreliable in whether this answer turns out to be the "right one". In a poster presented at the Winter Meeting of the Association of Physics Teachers, I reported on Alan's being positioned as the leader status despite not being a leader when it comes to grades (Conlin , 2008). Here we see the micro details of where being positioned as a leader is not just about taking the most conversational turns, but how everyone in the group epistemologically positions themselves to that person. This will lead them into trouble with respect to understanding the forces acting on the cart in what follows.

CHRISSIE: How'd'we /relate/ the two forces. Cuz it-

ALAN: Those two forces must be equal
CHRISSIE: Right, so it should be gravity is equal to...Now.
ALAN: Whatever
CHRISSIE: It should be-
ALAN: Whatever force you find there is the amount of force that you- that's um-
CHRISSIE: What do you mean what force
ALAN: That's the normal force.
DARIA: 10.68?
ALAN: That's what it is?
CHRISSIE: Ohhh I was gonna do this the wrong way.
ALAN: I mean, cuz, if those two forces are imbalanced that means the box is gonna fall.
CHRISSIE: Right.
ALAN: If they're equal that means it's about to fall, but it's gonna JUST make it across.
BRANDI: Tk Oh
CHRISSIE: Holdon say that again, if the two forces...
ALAN: Those two forces have to be equal. Otherwise it's gonna fall.
CHRISSIE: Ri:::ght in order to have acceleration right?
ALAN: In order- in order for it to...continue on in that circle. You know when you continue on in the circle (gestures)
CHRISSIE: Right, okay.
ALAN: /if/ those forces are out of wack (gestures that gets mirrored by Chrissie when the TA comes by)
CHRISSIE: or it's gonna move
ALAN: they're just gonna fly straight off or whatever...or something like that.
DARIA: Why is this so long...

Next, the Sparrows calculate the magnitude of the net force acting on the cart. Ultimately they get an answer, and Daria asks Alan if he thinks it is right:

DARIA: (to Alan) Do you think that's right?
ALAN: Mmhm. (nods). That's right.

At his point, Chrissie brings it back to sensemaking about the physical mechanism, and they immediately respond by sharing their ideas and collaboratively evaluating them:

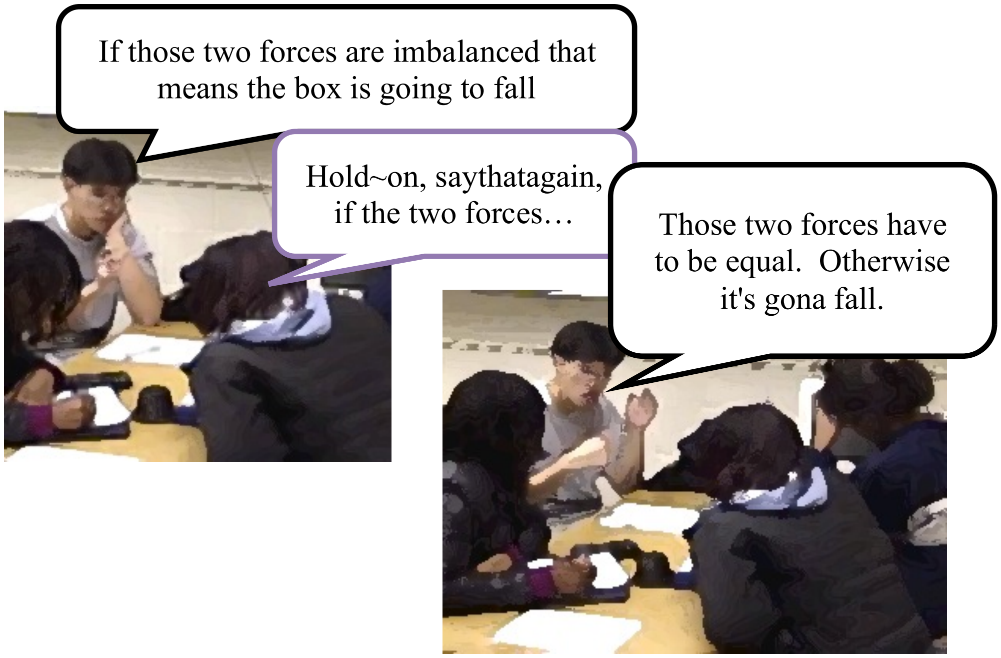

Figure 5.3—Alan's explanation is suspect here, but he and Chrissie treat it as "the" explanation.

Again, there is evidence of collaborative scientific sensemaking here, while also some room for improvement. Alan and Chrissie especially are working towards a shared understanding of the forces acting on the cart, sharing their ideas about their intuitive sense of the forces on the block. And once again, Alan is saying things matter-of-factly, and it gets taken up as an explanation rather than an idea about the world (see D. Kuhn, 2003, for a discussion of similar issues).

So, Alan's lack of epistemic distancing from his ideas left little room to sensemake. They are showing no signs at this point of detecting an inconsistency in their reasoning. They are alternately saying the forces are working together and that they are working against each other. (We saw the Bluebirds displaying similar mixed intuitions about the forces, particularly in Bree's explanation) Chrissie takes up Alan's idea as the explanation, and this is how they proceed. Luckily, TA Rosslyn comes by and catches this glitch in their reasoning and helps them recognize and address it. We do not know how it turns out, as the tape ends in the middle of TA Rosslyn's check-in.

Discussion Of The Sparrows' Longer-Term Dynamics—As reported in Chapter 4, the Sparrows at first are dismissive of the epistemological goals of the tutorial, until a tutorial instructor steps in to help them engage in some scientific sensemaking. He encourages them to help each other make sense of things such as unexpected bumps in the graph. He also "goes meta" to say *this discussion* is the sort of thing we want you to be doing. This interaction proves to be quite a formative moment for the Sparrow's shared understanding of the nature of how to engage with the tutorials. However, that shared understanding is not set in stone, and is vulnerable to perturbations (as the Ospreys helped us see with a new member challenging their norms with one sentence). And there are many mixed messages sent to these students in tutorial, some of which will threaten their understanding of tutorials that includes collaborative scientific sensemaking. And some of these threats will come from the tutorials themselves. Despite their bumpy trajectory of engagement with the tutorials, in the end the Sparrows, in the end, I would say they are quite a successful tutorial group.

The strange thing is although the Sparrows are a successful tutorial group in that they engage often throughout the semester in the practice of sensemaking, they are perhaps unhappily so. At a few times throughout the semester, they have "griping" sessions where they complain about the tutorials, and the course in general.

In these discussions, the Sparrows express a surprising amount of animosity. For example, after the first tutorial they get into a "gripe session" in which Brandi says "I don't like this," and Chrissie agrees with her. The others are sort of lukewarm about it, with Daria saying, "Yeah the physics labs are kind of funny…I'm sure they're gonna get harder," and Alan describing them as "elementary school stuff." So this episode highlights the issue as one that at the intersection of engagement, affect, and epistemology. The analysis of the Sparrows shows that the story can be a subtle one. Even though students express at times strongly negative emotions towards the tutorials, this does not necessarily derail them from engaging productively with the tutorial, in alignment with the curricular goals of collaborative scientific sensemaking.

CHAPTER CONCLUSIONS & DISCUSSION

In this chapter, I have presented two separate analyses to illustrate the dynamics of each groups' shared understanding that they should be collaboratively sensemaking about physics. The first example centered on the Sparrows and how they came to a shared understanding of tutorial in the face of contradictory messages about how they should sensemake, and about what. The TA told them to sensemake about any anomalies in the graph. As they are doing so later on in the tutorial, their sensemaking discussion got shut down when they realized the tutorial told them had told them to simply "smooth out the bumps". But then the other TA comes over and asks them about the bumps anyway, and they have a good answer for her because they have thought through it, and she rewards this behavior. So we see how the Sparrows progress towards more stably going to sensemaking in their discussions, although this progression is a somewhat bumpy one. One implication from this is where in the tutorial to place some epistemological cushioning.

This example of the Sparrows followed immediately from the analysis in Chapter 4, but does not extend too far into the semester. But what about the longer term dynamics? How do the groups end up at the end of the semester? To address this question I compared the approaches of the three groups to the same problem in Tutorial 9, using the episode as a touchstone to discuss each group's longer-term dynamics in turn. The Bluebirds are a spectacular group, and were soaring from start to finish in that they quickly went to sensemaking discussions and often returned to them throughout the semester. In Tutorial 9, they work together to establish a common force diagram of a cart upside-down on the loop-the-loop. When there is a discrepancy, they justify their ideas by drawing from intuitive sense of the physical interaction. The Ospreys, while they continue to have green mode discussions throughout the year, there is not nearly as much collaborative sensemaking about the physics. In Tutorial 9, they copy the force diagrams from their notes, and when a discrepancy arises they just drop it, without trying to make sense of the physics.

The analyses presented in this chapter characterize that the group's longer-term dynamics of sensemaking together in tutorials. The analyses reveal that all three groups continue to have sensemaking discussions throughout the semester, though the groups differ in the frequency and quality of those discussions. They also demonstrate the highly complex dynamics by which the groups' shared understanding of their activity evolves, with conceptual, epistemological, and affective tensions the students must manage. The analyses presented in this chapter contained further evidence that the students manage these dynamics simultaneously, by epistemically distancing themselves from their statements in ways that help the group maintain a safe space to make sense of physics together.

Chapter 6: Summary, Implications, and Future Directions

In this dissertation, I have characterized the dynamics by which tutorial students come to understand their activity as collaboratively making sense of physics. In this chapter I will briefly summarize the how each chapter has contributed to addressing the central questions introduced in Chapter 1, highlighting the key findings. Then I will discuss the implications of these findings for research, instruction, and curriculum design. I will conclude by suggesting some directions for future research.

SUMMARY OF KEY FINDINGS

In Chapter 1, I introduced two central research questions:

1. How do tutorial students build shared understandings of what it is they are doing in tutorial, particularly a shared understanding that they should be collaboratively making sense of physics?

2. How does that shared understanding evolve over the whole semester?

In Chapters 2 and 3, I lay the theoretical and empirical foundations for addressing these questions. In Chapter 2, I situated this research pursuit at the intersection of two literatures. Research on scientific argumentation in science classrooms as well as research on discourse analysis highlights the fact that to build shared understandings, students must balance making repairs of understanding while mitigating the affective damage that often accompanies such repairs.

In Chapter 3 I presented a qualitative and quantitative analysis of student groups to empirically establish the fact that the tutorial students are able to come to a shared epistemological understanding of what it is they are doing, i.e., an *epistemological framing* of their activity. They did not settle on one way of understanding their tutorial activity, but rather transitioned as a group between multiple ways of epistemologically framing their activity. I presented evidence that one of these framings showed more evidence for reasoning about mechanisms than the others, which enabled me to focus my analysis on the easily identifiable group discussions where sensemaking is likely to occur.

While the analysis of Chapter 3 established *that* the tutorial groups are able to build shared epistemological understandings of what they are doing in ways that involve making sense of mechanisms, it does not address *how* they are able to do so. I addressed this question in Chapter 4, through an analysis of three tutorial groups in their first discussion of the semester. I found that the groups were able to manage the epistemological and affective tensions of building shared understandings in part by maintaining epistemic distance between themselves and their statements. By softening their stance through hedging and ironic shifts in footing, all three groups were able to construct a safe space to sensemake. I found that the groups differed in the details of how they established this shared understanding, when in the tutorial it is established, and how it evolves from there.

I followed these longer-term dynamics in Chapter 5 by analyzing the discussions of all three groups throughout the semester. I found that while all of the groups continue to have sensemake discussions together throughout the semester, they differ from each other in how often and how stable their sensemaking discussions are. This variability highlights the complex nature of the evolution of the groups' interactions as they work to stay on the same page with respect to what they are doing together in tutorial. To illustrate these complex dynamics, I chose one group (the Sparrows) as they encountered mixed messages regarding whether they should be making sense of unexpected bumps in the graph. In the end, the Sparrows continued to sensemake about these bumps, even when the tutorial asked them to "smooth out the bumps." They did so with the help of a responsive TA that asked them to think about what might have caused the bumps despite the tutorial instructions, a finding that highlights distributed responsiveness an important aspect of the tutorial curriculum.

In sum, I have addressed each of the central questions by detailing the processes by which three tutorial groups built a shared understanding of their activity that included sensemaking. They accomplished this mutual understanding in part through the simultaneous management of epistemology and affect in order to make a safe space in which to share and evaluate ideas. I showed how each group got to this understanding in different ways and at different times. I also showed how their understandings evolved along different trajectories over the course of the semester. These findings have implications for research, instruction, and curriculum development, which I will discuss in the next section.

<u>DISSERTATION IMPLICATIONS</u>

Small things can make big differences

By zooming in on key moments of the turn-by-turn interactions uncovered, we can uncover details that prove to be consequential for the groups' longer-term dynamics, revealing the ways large-scale patterns can emerge from processes playing out at the level of a conversation. The analyses in Chapters 4 and 5 illustrate several ways that small things made big differences, including a TA who overheard an opportunity to get Sparrows sensemaking together, and a new group member who challenges the norms of the group by the way she words a question.

This sensitivity of the global dynamics to "micro" moments of interaction has implications for both research and instruction. For education researchers who study student interactions, this micro/macro connection brings with it a whole new set of methodological challenges, not least of which being how to go about connecting the micro and macro levels of analysis. The data set collected for the *Helping Students How to Learn* project, from which I draw my video, affords this sort of analysis because it contains longitudinal data over the course of the semester while also giving access to the group's micro-interactions. I have tried to show how micro moments can give insightful snapshots of the group's trajectory as they build shared understandings over the course of a discussion, a tutorial, and even a semester.

That these small moments can have such a broad impact has enormous consequences for both the instruction and design of tutorials. In Chapters 4 and 5 we have seen how in-the-moment TA decisions can have a tremendous impact on the group's sensemaking dynamics and thereby there engagement with and learning from the tutorials. The Sparrows were dismissive the tutorial before TA Joey overheard their conversation and pointed out an opportunity to collaboratively sensemake. From then on they continue to collaboratively sensemake regularly, throughout the rest of the semester. TA Joey's move forwarded the epistemological aims of the curriculum, but it was a random overhearing of a great question rather than a TA check-in or anything written on the tutorial worksheet.

Other influential TA moves we have seen are ones that contradict what is written on the worksheet. The Sparrows had been having a nice collaborative sensemaking discussion about until they saw the tutorial instructions to "smooth out the bumps," but TA Rosslyn asked the Sparrows about those bumps in the graphs anyway during her check-in. This resulted in the Sparrows receiving positive feedback for their efforts of having a sensemaking discussion, which helps stabilize their tendency to do so.

A qualitative analysis of the Bluebirds, the Sparrows, and the Ospreys over the entire semester reveals that the dynamics of the groups' framings of their activity are complex, and their path toward sensemaking together is nonlinear. Their understanding of their activity is challenged along the way when they encounter a variety of mixed messages about what it is they should be doing. This highlights the need for a responsive curricular tutorial environment, where an instructor can make informed deviations from the worksheet, for instance, when they overhear an opportunity to get a group sensemaking together. I will discuss elements of this distributed responsiveness in the next section.

Distributed responsiveness in the tutorial curriculum

In Chapter 5 I presented a case study of one group's bumpy road towards sensemaking, in which the Sparrows encounter contrasting messages about whether they should be sensemaking about some unexpected "jumps" in their motion graphs. This case shows how mixed messages may inevitable in such a flexible learning environment, and some of these messages may end up having unintended consequences. This also highlights the importance for *distributed responsiveness* across multiple aspects of the curricular context, including the tutorial instructors and the worksheets. I show how in several instances the TAs depart from the written instructions in order to take up an opportunity to engage the students in sensemaking, and these departures prove critical for the groups understanding that they should be making sense of the physical mechanisms.

The tutorial worksheets generally leave a lot of room for the students to take things in different directions. They are built in part to solicit and reward good scientific thinking, and not just "the right answers." However it is impossible for the tutorials to be infinitely flexible. Not only is every student is different, but in tutorial the learning trajectory of each group is bound together. And as we can see from the Sparrow's response to the instructions to "smooth out the bumps," a group's path towards sensemaking could occasionally encounter resistance from the tutorial itself, at least as it is written on the worksheet. But the worksheets are not the sole vehicle through which the tutorial curriculum is delivered. Through responsive teaching, TAs can attend to and assist the groups' progress in aligning with the epistemological goals of the tutorial, even if that occasionally means veering from the instructions written on the worksheet.

The coupled dynamics of epistemology and affect

In Chapter 2, I argued how in building shared understandings, the groups would have to find ways to manage the affective dynamics when making repairs, in order to create a space where the groups feel comfortable to introduce and evaluate each other's ideas. In Chapter 4 I showed how the groups manage these epistemological and affective dynamics through epistemic distancing, i.e., by softening their stance through hedging and other shifts of footing. This distance offers protection from affective damage if the idea is repaired or rejected, and can make or break a discussion. In the Bluebird's first discussion, for example, Bree reads her own response in an ironic register, distancing herself from its content in a way that sparks laughter and ultimately helps the group ease from reading what they wrote into saying what they think. In the Ospreys' first discussion, in contrast, Adam flatly states his response, "it's been proven that you learn from your mistakes" and the conversation ends there.

The deep connections between affect and epistemology explored in the analyses of Chapter 4 and 5 have implications for both research and instruction. I have introduced epistemic distancing as a means to capture the dynamics of epistemology and affect in the tutorial groups' discussions. I have identified several instances in classroom video where students use epistemic distancing as a resource to navigate the epistemological and affective dynamics simultaneously, and in ways that proved to be quite productive for the group's sensemaking discussions. But the use of appropriate distancing from one's claims, e.g. via hedging, is more than just a helpful tool for making a safe space to sensemake. It is also an important element of scientific practice, and one that deserves more attention from science education researchers and science educators.

One consequence of affect playing into the epistemological dynamics of the tutorial groups is that tutorial instructors and curriculum developers can and should attend to affect in designing the curriculum, whether it be on paper or in the moment. At this early stage of exploring this connection, however, recommendations for instruction should be made only with caution, and should be grounded in evidence from classroom data of the sort presented in this dissertation. Based on the evidence I have presented, I can suggest a few small tweaks that could have a big difference. For example, I showed in Chapter 4 how the Bluebirds and Ospreys relied on turn-taking to structure their first discussion, whereas the Sparrows bypassed the turn-taking and their discussion faded quickly. The question could be slightly reworded to encourage turn-taking with something like "read your responses, noting similarities and differences," utilizing the turn-taking structure to get more ideas out there while allowing the students to ease from reading what they wrote to saying what they think.

Based on my findings about the connections between affect and epistemology, I suggest that the tutorials could stand to be a little more explicit about how the groups' sensemaking activities reflect the disciplinary practices of science. If they understanding what they are doing as authentic to what scientists are doing, this could mitigate some of the negative affective responses of the students towards the tutorial, which at times can come across to them as condescending (Brad), or as “baby work” (Chrissie).

OPEN QUESTIONS AND FUTURE DIRECTIONS

The research reported in this dissertation has raised new questions, some of which were addressed, while others remain open questions to be pursued in further research. For instance, I have only begun to address the longer-term dynamics of the groups. While we saw an increase in collaborative sensemaking for each group at the very beginning of the semester, tracking these dynamics over the course of the semester will take considerably more work.

My dissertation has also touched upon broader issues too big to adequately address at this time, but would be fruitful future directions to pursue. For instance, there is the issue of how the shared understandings at the group level impact individual students’ learning. Following the long-term dynamics of the groups by piecing together micro moments, we can show evidence of the individuals learning from their group interactions, but in order to make sure the individual students access this learning beyond the tutorial would require supplemental data such as tests or homework assignments.

Another issue raised but insufficiently addressed in this dissertation is how the students’ shared conceptual and epistemological understandings interact. How does the shared framing of *having a discussion*, for instance, impact the sort of conceptual understandings the groups build? There is also the question of the how the groups’ multiple shared framings of tutorial fit together within a broader understanding of tutorial. Goffman (1974) characterizes frames as embedded, as in the layers of lamination of talk revealed when the speakers shift their footing, but little research has aimed to fill in the story of how frames can be nested.

In Chapter 5 I took one step towards filling in that story for the Sparrows by showing how their practice of reading the tutorial worksheet aloud helped them to stay on the same page, both figuratively and literally. This practice suggests that the Sparrows are forming an understanding of the tutorial whereby they are working together towards a common purpose that involves staying on the same page, as well has having discussions. The Bluebirds also frequently display this sort of behavior, but the Ospreys do not. This makes me suspect that this reading-out-loud phenomena could turn out to be a sign of a well-functioning tutorial group. But exploring this question would require expanding the data analysis beyond just the times surrounding discussions, and so must be left as a future direction.

One last major issue raised in this dissertation that deserves further research is the students' use of humor and irony to navigate the epistemological and affective dynamics of collaborative scientific inquiry. Based on the dry, emotionless world of science painted by philosophers and history of science, one might naively suspect that humor and laughter have no place in the doing of science. Or that if they do play a role, the effects would be too subtle and too secondary to warrant attention from educators or education researchers. This would explain the strangely sparse literature on the use of humor in education. However, this perspective is a flawed one, as the evidence presented in Chapters 4 and 5 suggests.

I presented multiple instances in which the students used humor and irony in ways that assisted their collaborative sensemaking. First, humor helps the group work together, a well-documented benefit of humor within the research on small groups (e.g., Fine & Soucey, 2005; Gottman, 1993). What is lacking in the research are studies detailing the processes by which humor helps accomplish their goals, especially when those goals include *learning*. Although space considerations prevented me from giving due consideration of this point, by providing evidence of such processes my dissertation and work extended from it can contribute to the literature. In Chapters 4 and 5 I have examples of students mockingly reading out from the tutorial instructions as way to enter into discussions that are conducive for scientific discussion.

Humor and irony help students make repairs of understanding while simultaneously managing affect. For example, students like Bree can distance themselves from their ideas, thereby protecting affect in the case that the ideas are repaired or rejected. Thus, the evidence presented in this dissertation hints that humor, laughter, and irony are not just "social lubricants" but can play a substantive role in the doing of science and in building shared understandings more generally. Humor and laughter can also be productive empirical tools for the researchers of student interactions; sharing a laugh can be perhaps one of the most dramatic ways of signaling shared understanding. This is a point that the great physicist Richard Feynman (1988, p. 16) expressed eloquently: "[T]he highest forms of understanding we can achieve are laughter and human compassion."

Appendix A – Transcription Conventions

I transcribe talk using a variant of the Jefferson transcription system (Sacks, Schegloff, & Jefferson, 1974, pp. 731-733).

Sign	Description	Example
/ /	Indicates uncertainties in the transcript, for instance when audio is unclear or low in volume	S1: Sshh…/let's whisper/ S2: What?
Boldface	Indicates some form of emphasis, which may be signaled by changes in pitch *and/or* amplitude.	**What** did you say**?!**
[	A left bracket connecting talk on separate lines marks the point at which one speaker's talk overlaps the talk of another.	S1: Haa[ppy birthday to you… S2: [happy birthday to you…
]	A right bracket marks the place where the overlap ends.	S1: [I wasn't finished] S2: [I have one more] thing to say
~	Tildes between words are used to mark rapid speech.	Wicked~fast~talk
:	Colons indicate that the sound (or silence) just before the colon has been noticeably lengthened.	NO::::: I wasn't saying that. What's going on there? :: Any ideas?
-	A dash denotes a sudden cut-off of the current sound.	Say wha-?
. ? ,	*Punctuation symbols are used to mark intonation changes rather than as grammatical symbols:*	
.	A period marks a falling contour.	But who knows.
?	A question mark indicates a rising contour.	You know, like, valley speak?
,	A comma indicates a falling-rising contour.	Well, I guess,
(.6)	Numbers in parentheses mark silences in seconds and tenths of seconds.	Okay… (1.6) I got it.
*hh	A series of "h"s preceded by an asterisk denotes an inbreath.	*hhh You scared me!
(*comment*)	• *Italics* in parentheses indicate actions accompany the talk being transcribed.	*(points to worksheet)*
Contiguous= =talk	• An equals sign is used to indicate "latching"; there is no interval between the end of a prior unit and the start of a next piece of talk.	S1: Objects in motion= S2: =stay in motion. T: That's right!
CAPITALS	Indicate increased volume.	Turn it UP!

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