Contributing to Meaning Making: Facilitating Discourse in the High School Physics Classroom

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Abstract

The Next Generation Science Standards (NGSS) identify eight practices as essential to science and engineering, and these practices include asking students to construct explanations, to engage in argumentation, and to communicate scientific information. However, few teacher-training programs instruct teachers how to facilitate such discourse in the classroom. Modeling Instruction is one movement in physics education that organizes high school physics content around a small number of student-derived scientific models, and it relies on student discourse for the design, development, and deployment of these models.

This research is a self-study of one high school physics teacher's experience facilitating large group discourse in the high school modeling physics classroom. Whiteboard meetings and graded discussions were examined by applying the analytical framework created by Mortimer and Scott (2003) to characterize the classroom talk and the discourse facilitation moves that I employed. In addition, elements of discourse analysis were used to examine some of the tensions that I experienced in the facilitation of this discourse.

The findings suggest that deliberate identification of the teaching purposes for the discussion can help determine the scaffolding needed for students to enter the Discourse (Gee, 2011) of being a participant in these large group conversations. In addition, connecting the dialogic dimension of exploring student ideas with the authoritative dimension of introducing the scientific view and supporting the internalization of that view is necessary to contribute to meaning making in the science classroom.

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Chapter 1 : Introduction

Rationale

In 1996 the National Research Council (NRC) released the *National Science Education Standards* (*NSES*) in an attempt to spur science education reform across the United States. One recommendation in the *NSES* stated that teachers should "encourage informal discussion and structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of one another" (NRC, 1996, p.50). In addition, the *NSES* mentioned the social nature of science when it described how "peer review is an important aspect of science" (NRC, 1996, p.174). In this document, the promotion of scientific discourse is evident.

In 2012 the National Research Council published *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas,* with the introduction to the *Framework* justifying its release because of the new understandings both in science and in teaching and learning science that have developed since the *NSES* (NRC, 2012). Three of the *Framework's* eight Scientific and Engineering Practices - (6) Constructing explanations, (7) Engaging in argument from evidence, and (8) Obtaining, evaluating, and communicating information - emphasize the role of and the participation in scientific discourse. Again, the promotion of scientific discourse is evident.

Moreover, the 2012 *Framework* elaborates on the social aspect of science, stating that science "is fundamentally a social enterprise, and scientific knowledge advances through collaboration and in the context of a social system with well-developed norms" (NRC, 2012, p.27). For instance, science involves the practice of peer review, stating how scientists "exchange emails, engage in discussions at conferences, share research techniques and analytical procedures, and present and respond to ideas via publication in journals and books" (NRC, 2012, p.27). This social emphasis is not new in the field of science, nor is it new in education research; Ball and Cohen (1999) describe how thoughtful discussion among learners is "an essential element of any serious education, because it is the chief vehicle for analysis, criticism, and communication of ideas, practices, and values" (p. 13). Likewise, researchers adhering to situated learning theory recognize that *cognition is social*, and "interactions with the people in one's environment are major determinants of both what is learned and how learning takes place" (Putnam & Borko, 2000, p. 5).

So while the social aspect of learning is not new, its explicit application to the high school science classroom does represent a different emphasis then the conceptual change efforts found in science education research in the 1980s and 1990s. Specifically, in those earlier efforts learning has been viewed as a model of an individual's conceptual change; for instance, Posner, Strike, and Hewson (1982) proposed how learning was not simply seen as the addition of new pieces of information, but rather the interaction of new knowledge with existing knowledge. If a student's existing knowledge is not enough to allow him or her to grasp any new phenomenon successfully, he or she must reorganize or replace their central concepts as long as the new conception was intelligible, plausible, and fruitful in the mind of the individual. However, rather than focusing on the individual as the basic unit of analysis, situative perspectives “focus on interactive systems that include individuals as participants, interacting with each other as well as materials and representational systems” (Putnam & Borko, 2000, p. 4). This social emphasis supports that idea that learning “is not a unidirectional phenomenon; the community, too, changes through the ideas and ways of thinking its new members bring to the discourse” (Putnam & Borko, 2000, p. 5).

If this understanding of cognition asserts that meaning-making and learning occur through the interaction of individuals with each other and with materials and representational tools, we would expect schools, our primary places of learning, to promote rich discourse as much as possible to maximize student learning. Unfortunately, this is has not been so. Hoetker and Ahlbrand (1969) reviewed studies of classroom verbal patterns from the first half of the twentieth century and found remarkable persistence of the teacher-dominated question and answer interaction pattern. Mehan (1979) identified the prevalence of teacher-student-teacher sequences in which the teacher provides an initiation (*I*), a student replies (*R*), and the teacher evaluates (*E*) this response; this *I-R-E* sequence is used for both directing procedural activities and also delivering content. Lemke (1990) calls this pattern Triadic Dialogue and he discusses how science classroom discourse is still dominated by this same well-known pattern. Observational studies show that teacher-led question and answer interactions still dominate discourse patterns (Newton, Driver, & Osborne, 1999) and when large group discussions are attempted the majority of student contributions are single words, phrases, or short sentences without reasoning or explanations (Pimentel & McNeill, 2013).

Teacher talk and the triadic dialogue still dominate classroom discourse because of a lack of expertise on both the part of students and teachers. Students often have a lack of experience with discussion or a lack of knowledge about the content being discussed (Nassaji & Wells, 2000; Pimentel & McNeill, 2013; Alozie, Moje, and Krajcik, 2010). Teachers often do not feel capable of effectively engaging students in whole class discussion (Driver, Newton, & Osborne, 2000; Pimentel & McNeill, 2013) and they struggle to connect the disciplinary concepts to the everyday lives of students to promote discussion (Alozie, Moje, & Krajcik, 2010). Practically speaking, teachers often avoid large group discussion either because they feel constrained by time and the need to 'cover' as much content as possible (Alozie, Moje, & Krajcik, 2010; Tobin, McRobbie, & Anderson, 1997) or they simply feel like discussion would lead to losing control of the class (O'Brien, Stewart, & Moje, 1995; Newton, Driver, & Osborne, 1999). Sometimes teachers have tried to implement discussion but have been unsuccessful because they provided little guidance to the students how to undertake it effectively (Driver, Newton, & Osborne, 2000).

Statement of the Problem

If science is to be represented in the classroom as a social enterprise that "advances through collaboration and in the context of a social system with well-developed norms" (NRC, 2012, p. 27), then teachers need strategies and approaches that promote scientific discourse. Modeling Physics Instruction (Hestenes, 1996) is one approach intended to engage students in such a social system through its promotion of scientific discourse. In the process of designing, developing, and deploying a coherent set of models to describe the natural world, the instructor "guides the students to a deep understanding of the principles by asking leading questions and encouraging discussion among the students in class" (http://modelinginstruction.org). Some research on the experience of facilitating discourse has been done (van Zee & Minstrell 1997a, 1997b; van Zee, Iwasyk, Kurose, Simpson & Wild, 2001; Hammer, 1995; Scott, Mortimer & Aguiar, 2006). In addition, other research has been conducted that is specific to discourse in modeling instruction at the university level (Desbien, 2002) or to the framing of discourse in modeling instruction (Megowan, 2007). However, there is a gap in the research about facilitating large-group discussions in the high school modeling classroom.

Research Questions

I am a high school physics teacher who implements Modeling Instruction and who is interested in promoting such scientific discourse in my classroom. I have attempted to implement classroom discourse norms of presenter and audience member etiquette (Magnusson, Palinscar, & Templin, 2004) and of the instructor providing non-evaluative feedback when appropriate (Alozie, Moje, & Krajcik, 2010) in an effort to create a culture conducive to discourse (Driver, Newton, & Osborne, 2000). However, a closer look at those discursive experiences revealed not only the degree of student voices present in the discussions but also the tensions I experienced facilitating that discourse. This self-study was designed to contribute to the literature about facilitating large group discourse in the high school physics classroom. It explored and analyzed my teaching practice, considering both what I had hoped from my students' discourse and the reality of what transpired. The questions that guided this research were:

- How does my facilitation of classroom discourse contribute to meaning making in the high school Modeling Physics classroom?
- What tensions do I experience in the facilitation of this discourse?

Potential Significance of the Study

This is an intense examination of my teaching practice, warts and all. It lies at the intersection of my understanding of the role of scientific discourse, Modeling Instruction, and the Science and Engineering Practices detailed in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. I hoped that through analyzing the facilitation of discourse in my classroom I could contribute to the literature about how science teachers can work toward the creation of a social system with well-developed discourse norms. And although I expected that the analysis might provide insight that resonates not only with experienced Modeling Instruction teachers and with teachers curious about Modeling Instruction, I hope it benefits any teacher interested in enhancing scientific discourse in his or her classroom. By reflecting on the tensions I experienced during discourse, this work might move teachers in some small part toward the collaboration and the social system of science espoused by the *Framework*.

Overview of the Following Chapters

Chapter II is an overview of the relevant literature; it provides theoretical background about the role of discourse in the classroom, it presents an overview of efforts to reform physics instruction, and it identifies examples of other self-studies in the science classroom. Chapter III describes the research methods used to conduct the self-study. It begins with a synopsis of Modeling Instruction and a description of the setting and participants involved. It then discusses the analytical framework used with two genres of large group discussion, and it concludes with an overview of how the discourse analysis was conducted. Chapter IV presents and discusses the findings for the two genres of large group discourse. I then discuss conclusions and implications in Chapter V.

Chapter 2 : Review of Relevant Literature

In this chapter I present literature relevant to this study. As context for the study, I begin by discussing the theoretical background of discourse and its role in schools. Second, I describe the specific role of talk in the science classroom. Third, I present some examples of different modes of discourse, namely the triadic dialogue, exploratory talk, and argumentation. Fourth, I describe physics curricular reform efforts that have incorporated student discourse. Fifth, I share some research about classroom discourse in practice; specifically, I consider experiences facilitating discourse, scaffolding, research on assessing discourse, and research about factors influencing teacher willingness to change teaching methods to enhance in the implementation of student discourse in the classroom.

Theoretical Background

The basic function of school occurs through communication (Barnes, 1975; Cazden, 2001), and the daily school experiences of students and teachers are permeated by oral, written, and nonverbal communication. Spoken language "is the medium by which much teaching takes place, and in which students demonstrate to teachers much of what they have learned" (Cazden, 2001, p. 2). In fact, Mortimer and Scott (2003) claim "if you wish to investigate the ways in which people typically *think* about the world around them, the place to start is to investigate the ways in which they *talk* and communicate about the world" (p. 10).

To better understand what is happening through talk, this work relies heavily on Vygotsky's (1978) perspectives on development and learning. For Vygotsky, "every function in the child's cultural development appears twice; first, on the social level, and later, on the individual level; first, *between* people *(interpsychological),* and then *inside* the child *(intrapsychological)*" (p. 57). This primary role of the social is not isolated to one form of learning, but Vygotsky states that it "applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals" (p. 57). Mortimer and Scott (2003) reiterate Vygotsky's view clearly by stating that "all learning originates in social situations, where ideas are rehearsed between people mainly through talk. As the talk proceeds, each participant is able to make sense of what is being communicated and the words used in the social exchanges provide the very tools needed for individual thinking" (Mortimer & Scott, 2003, p. 3).

It is the transformation, then, from the social plane to the individual plane where classroom talk matters, and Vygotsky states how this transformation "is the result of a long series of developmental events. The process being transformed continues to exist and to change as an external form of activity for a long time before definitively turning inward" (Vygotsky, 1978, p. 57). Various modes of classroom talk provide such developmental events, these social situations where "ideas are rehearsed between people, drawing on a range of modes of communication, such as talk, gesture, writing, visual images, and action" (Mortimer & Scott, 2003, p. 9). As these ideas are rehearsed, individuals "reflect on, and make individual sense of, what is being communicated" (p. 9). When we realize this social nature of learning, "it does not seem so surprising that students should collaborate in coming up with an answer to a question or a solution to a problem" (Lemke, 1990, p. 79). Likewise, this intimate relationship between talking and thinking becomes very apparent when we start 'talking to ourselves' or 'thinking aloud' about difficult, or stressful, problems (Mortimer & Scott, 2003).

In addition to Vygotsky's perspective, this work is also informed by sociocultural theory (Wertsch, 1991). Here the basic assumption is that all mental actions are inevitably situated in cultural, historical, and institutional settings and what is accepted as knowledge and teaching and learning in school science is related to those settings (Mortimer & Scott, 2003). We can only understand the processes of teaching and learning in a specific school if we are able to examine their social, cultural, and historical contexts (Mortimer & Scott, 2003).

The field of social semiotics also informs the analysis of the discursive interactions between teachers and students; social semiotics is a field whose basic quest is an understanding of how people make meaning (Lemke, 1990). By looking at the words, gestures, symbols – everything people do in community – social semiotics attempts to understand interpretations of how and why people make meaning of those actions. A key assumption of social semiotics is that "meanings are *made*" (Lemke, 1990, p. 186). Just as the interactions in a classroom are situated in the culture of that time, the words and phrases used do not have inherent meaning in and of themselves, but rather the meanings are constructed in the moments in which they are used.

Overall, then, this self-study is situated in the intersection of Vygotskian learning, sociocultural theory, and social semiotics. It is Vygotskian in the sense that it examines people using talk to rehearse ideas and make meaning, it is sociocultural because the meaning making is situated within a particular culture and context, and it is socially semiotic because it analyzes the meanings that students construct for words and phrases in the discussions being studied. Because this study is based on facilitating discussions in a science classroom, the next section specifically considers the role of talk in the science classroom.

Talk and the Science Classroom

Historically, talk has always had an important position in science teaching. Lemke (1990) reminds us that any new theory "always begins as *somebody's* way of talking about a topic or problem" (p. 125). Science is inherently a social practice (Mortimer & Scott, 2003), because science always involves taking "ways of talking, reasoning observing, analyzing, and writing that we have learned from our community and use them to construct findings and arguments that become part of science only when they become shared in that community" (Lemke, 1990, p. xi). These behaviors have resulted in the creation of what Bakhtin (1981) calls a *social language* of science, "a discourse peculiar to a specific stratum of society within a given social system at a given time" (p. 430). Learning science, then, involves learning the social language of science (Mortimer & Scott, 2003). We learn this language "in much the same way we learn any other: by speaking it with those who have already mastered it and by employing it for the many purposes for which it is used" (Lemke, 1990, p. 1).

In his seminal work, *Talking Science,* Lemke (1990) uses the theory of social semiotics to better understand how resources of language are used in talking science. He states that structurally, science dialogue "has two patterns: an organizational pattern, represented by its activity structure, and a thematic pattern" (p. 13). The activity structure is the sequence of moves that make up a portion of a lesson, and the thematic pattern is the combination of words and/or symbols that enable people to construct complex meaning about a topic. Lemke emphasizes the role of semantics in thematic patterns, because "any particular concept or idea only makes sense in terms of the relationships it has to other concepts and ideas" (p.*ix*). For instance, while teachers often discuss the importance of vocabulary and key science terms, Lemke emphasizes what is critical is "the *use* of those terms in relation to one another, across a wide variety of contexts. Students have to learn how to *combine the meanings* of different terms according to the accepted ways of talking science" (Lemke, 1990, p. 12). To assist us in using scientific language and constructing meaning, we "construct systems of meanings by using language, mathematics, diagrams, and techniques" (p. 185). Lemke comments on how little classroom dialogue "is devoted to the exposition of the patterns, to explicitly telling students just what the relationships of key terms are and how those relationships fit into a larger pattern" (p. 22). What usually occurs, teachers "simply *use* the meaning relationships, and the outward signs as to what those relationships are can be quite subtle" (p. 22). Students are not exposed to the specifics of the social language of science.

What complicates matters is that from birth, each one of us is immersed in an *everyday* social language. This is the language "that provides the means for day-to-day communication with others, that provides a way of talking and thinking about all that surrounds us" (Mortimer & Scott, 2003, p. 13). The everyday social language and the science social language often conflict, and learning the social language of science necessitates understanding “the specific relationships of scientific meanings to one another, and how those relationships are assembled into thematic patterns” (Lemke, 1990, p. 21). Students need to learn that the scientific language is a specific way of talking about the world; teachers need to recognize they are expected both to be proficient in this specific language and to guide students to proficiency in this language.

Modes of Classroom Talk

Triadic dialogue. Teachers, as experts, have the authority in classrooms; they manage the discourse that occurs. In fact, teachers alone “have the role-given right to speak at any time and to any person; they can fill any silence or interrupt any speaker; they can speak to a student anywhere in the room and in any volume or tone of voice” (Cazden, 2001, p. 82). They get to decide which students will answer which questions and to say which answers are correct” (Lemke, 1990, p. 11). Yet, even with this authority, and the related opportunity this authority entails, the most pervasive mode of discourse that occurs in classrooms is the *I-R-E* sequence (teacher *initiation* – student *response* – teacher *evaluation*) (Mehan, 1979; Cazden, 2001) that Lemke (1990) calls the triadic dialogue. A challenge with triadic dialogue is that it does not typically reveal what people think about the world around them. Rather, most of what students say “tends to be fit into the thematic pattern set up by the teacher’s Preparation and Question moves, and students have little opportunity to make semantic connections in their own terms” (Lemke, 1990, p. 32).

Not all classrooms are confined to the discourse mode of triadic dialogue; the next section highlights some approaches that have been used to incorporate discourse in classrooms. First, the notion of exploratory talk is discussed, followed by a discussion of the research on argumentation.

Exploratory Talk. Some classrooms have incorporated more student discourse by framing student contributions through the perspective of exploratory talk. Exploratory talk is analogous to the 'rough draft' of speaking, and in environment promoting exploratory talk instructors encourage students to make discursive contributions knowing that those statements will be imperfect. Exploratory talk (Barnes, 1992, 2008) "is hesitant and incomplete because it enables the speaker to try out ideas, to hear how they sound, to see what others make of them, to arrange different information into different patterns" (Barnes, 2008, p.5); it. Contrastingly, in presentational talk, the speaker's attention is "primarily focused on adjusting the language, content, and manner to the needs of an audience" (p.5). Such talk frequently occurs "in response to teachers' questions when they are testing pupils' understanding of a topic that has already been taught" (p.6). By communicating the expectations of exploratory versus presentational talk, students are aware of the discourse mode and can compose their statements accordingly. For example, by promoting an environment consisting of exploratory talk, Pierce and Gilles (2008) enabled elementary and middle school students to engage in critical conversations, discussions in which students addressed social and ethical issues that affect them. Likewise, in their mixed methods analysis of classrooms emphasizing exploratory talk, Mercer, Dawes, Wegerif, and Sams (2004) observed an improved use of indicator words, increased utterance length, and higher reasoning scores compared to classrooms without an emphasis on exploratory talk. Overall, being explicit about the nature of the classroom talk and providing space for students to engage in exploratory talk has shown improvements in the quality of student contributions in the classroom.

Argumentation. Another avenue for including discourse in the classroom has been the incorporation of argumentation into science classrooms. Toulmin (1958) defined an argument as an assertion and its accompanying justification. His well-known model for argumentation includes the data, claim, warrant, and backing. The data are the facts used by participants in support of their claim, and the claim is the conclusion trying to be established. Reasons given to justify the connection between the claim and data are the warrants, and backings are the particular assumptions that agreed upon and support the warrants. Walker and Sampson (2013) apply this framework to science and differentiate between scientific argumentation and a scientific argument by stating scientific argumentation "requires individuals to analyze and evaluate data and then rationalize its use as evidence for a claim. A scientific argument, on the other hand, consists of a claim supported by evidence and a rationale" (p. 564).

Argumentation is especially pertinent in science classes. It is important "to develop children's ability to understand that argument and uncertainty are elements that are inherent to science, and that argument itself is a normative practice" (Osborne et al., 2013, p. 322). Driver, Newton, and Osborne (2000) challenge the common "positivist view" of science in which nature is understood by simple observation and experiment and promote the reconceptualization of the practices of science teaching "to portray scientific knowledge as socially constructed" (p. 289). The body of knowledge that is considered to be the scientific view has been constructed through the social process of argumentation.

Driver, Newton, and Osborne (2000) validated argumentation's place in the science classroom because argumentation is necessary to give fair account of this social nature of science.

Acknowledging the role of argumentation in science education has resulted in efforts to teach argumentation. Zohar and Nemet (2002) found that explicit teaching of argumentation increased student performance both in science content knowledge and in the process of argumentation. Kuhn (2010) taught argumentation through experience rather than through explicit instruction and found some transfer between the argumentation of social issues and the argumentation of scientific issues. Sampson and Clark (2009) compared the effect of student group on argument quality and they found that students who worked in a group produced significantly better arguments than the students who worked alone. Walker and Sampson (2013) used an argument driven instruction model to examine how students' ability to argue evolved over the course of semester.

As a result of teachers attempting to teach argumentation, studies have shown that students typically struggle with scientific argumentation. McDonald (2010) found that argumentation improves through use of socioscientific contexts, but students struggled a little more in argumentation over scientific concepts. Generally speaking, argumentation in socioscientific contexts "does not place the same conceptual demands on participants, as they can apply informal knowledge gained through previous life experiences to support and justify their arguments" (p. 1158). In scientific contexts, however, students might not feel confident in the requisite content knowledge, and that "perceived lack of scientific content knowledge may hinder participants' engagement in argumentation tasks" (p. 1158). The argumentation involved in these discussions is scientific and thus does require some prerequisite content knowledge. In addition to content limitations, students also struggle with the process of scientific argumentation; Sampson and Clark (2009) argue that students lave a limited understanding of the goals and processes of scientific argumentation and how these goals and processes diverge from the forms of argumentation to which they are accustomed. Students are not a tabula rasa with regard to argumentation; Sampson and Clark (2009) discuss how students bring resources for argumentation to the classroom from everyday experiences, but they struggle "making sense of data, generating appropriate explanations, justifying these explanations, and explaining their reasoning in alignment with the theoretical practices of the scientific community" (p. 453).

Researchers have provided suggestions for improving argumentation instruction. For example, McDonald (2010) recommended that "argumentation scaffolds should be used in conjunction with explicit argumentation instruction to ensure participants are familiar with the various definitions and meanings of argumentation components, such as data, claims, warrants, rebuttals, etc." (p. 1158). Walker and Sampson (2013) called for the crafting of arguments consisting of an explanation supported with evidence and using a medium such as a whiteboard to show in a manner visible to others the evidence used. Driver, Newton, and Osborne (2000) state that simply providing the activities to practice this discourse is paramount; specifically, "science education must give access to these forms of argument through promoting appropriate classroom activities and their associated discursive practices" (Driver, Newton, and Osborne, 2000, p. 288). Moreover, "This process of enculturation into science comes about in a very similar way to the way a foreign language is learned—through its use. Students need opportunities not just to hear explanations being given to them by experts (teachers, books, film, computer programs), but they also need to practice using the ideas themselves to gain confidence in their use, and through this process develop a familiarity with, and understanding of, scientific practices and ways of thinking" (p. 298). Any science instructor, then, should consider the explicit, scaffolded instruction of argumentation as necessary to promote the practices of science and its construction of knowledge.

Overall, argumentation has been an area of education research (and science education research) that has promoted the development of discursive moves in a mode other than the triadic dialogue. In the next section, efforts to encourage scientific discourse specifically in the physics classroom are discussed.

Pedagogical Reform Efforts in Physics Education

In the last several decades, there have been efforts to reform physics instruction to improve its effectiveness and move away from traditional lecture mode of content delivery. For example, in *Workshop Physics* (Laws, 1991), students are placed in pairs and work with computers to perform experiments and work through activities throughout each class period. Classes are held in three two-hour periods per week, and most of the student time is spent performing experiments, making observations, and building mathematical models of their findings. Some class periods may include brief lecture segments or whole- class discussions. Although the reform is focused on increasing student's use of empirical experience it is not focused specifically on student discourse, although the use of small groups inherently increases student conversations over traditional lecture methods.

Similar to Workshop Physics, *Physics by Inquiry* (McDermott, et al., 1996) is a curricular reform effort that places emphasis "on discovering rather than memorizing and in which teaching is by questioning rather than telling" (p. iv). This laboratory-based curriculum consists of a variety of modules, and each module encourages the student to intellectually engage in the lessons as they are guided through the process of developing a conceptual model from hands-on activities (Shaffer & McDermott, 1992). Instructors do not lecture but circulate as students work through experiments and exercises, engaging students in "dialogues that permit in-depth questioning" (Shaffer & McDermott, 1992, p. 1011). The patterns of these interactions are prescribed; when a student asks a question, the appropriate response of the instructor is "not a direct answer, but another question that can help the [students] through the reasoning necessary to arrive at their own answers" (McDermott, 1990, p. 739); student discussion has replaced the Triadic Dialogue as the discourse norm.

Peer Instruction (Mazur, 1997) is an interactive engagement strategy that has resulted in students demonstrating performance gains; it requires each student to apply the core concepts being presented, and then to explain those concepts to their fellow students. During instruction, students are given one or two minutes to formulate individual answers to conceptual questions and report their answers to the instructor using an electronic student response system. Students then discuss their answers with others to explain their underlying reasoning and are surveyed again (Crouch & Mazur, 2001). Lasry, Charles, Whittaker, and Lautman (2009) explored whether other cognitive and metacognitive processes such as reflection or time-on-task could explain such gains. Conducting a study in which one group used Peer Instruction while other groups experienced combinations of reflection and intentional distraction, they observed that peer-discussions provided "the greatest increases in rates of correct answers" (p. 183). Interestingly, peer discussions result in increased performance "even if no one student in the group knows the correct answer at the beginning of a discussion" (p.183). Similarly, in a larger study, Hake (1998) examined the performance of over 6000 college physics students according to the teaching strategies they experienced as physics students. He categorized those strategies which "yield immediate feedback through discussion with peers and/or instructors" (p.65) as Interactive Engagement strategies, and he found that traditional passive-student introductory physics courses "imparted little conceptual understanding of Newtonian mechanics" (p.64) while the use of Interactive Engagement strategies "can increase mechanics course effectiveness well beyond that obtained with traditional methods" (p.74). Discussion is what makes these methods interactive; the presence of discussion in these interactive engagement methods is consistent with our developing understanding of the importance of discourse in learning science.

While much of this research has been conducted at the university level, reform is also happening at the high school level. Modeling Instruction is the largest high school physics education reform effort to date. In 1987, Hestenes posited "mathematical modeling should be the central theme of physics instruction" (p. 453). He called for reorganization and a prioritization of physics content that would emphasize coherence, so he proposed "organizing course content around a small number of basic models" (Hestenes, 1996, p.1). The outcome of this effort organizes high school physics content into a coherent framework of models that are created from students engaging in modeling cycles. In a complete modeling cycle of model design, development, and deployment:

> students are required to present and justify their conclusions in oral and/or written form, including a formulation of models for the phenomena in question and evaluation of the models by comparison with data. Technical terms and representational tools are introduced by the teacher as they are needed to sharpen models, facilitate modeling activities and improve the quality of discourse (Hestenes, 1996, p.6).

This approach has gained in popularity because "students learn best from activities that *engage* them in actively constructing and using structured representations to make sense of their own experience and communicate with others" (Hestenes, 1996, p.18). Teachers participating in Modeling Physics workshops experience scientific discourse that this approach incorporates while also learning how to facilitate such discourse in their respective classrooms.

Teachers implementing Modeling physics have even altered how they facilitate discourse in their modeling instruction courses. In his modification of Modeling discourse, Desbien (2002) introduced Modeling Discourse Management, an approach to assist teachers in implementing this high school reform effort at the university level. In the traditional Modeling sequence, groups present findings from their laboratory activities through small group presentations. Desbien modified this approach by having the student groups arrange themselves in a circle to promote a whole group discussion. In this approach the instructor remains outside the circle during the discussion, and if the instructor wishes to contribute to the role he or she must take a place in the circle. Desbien claims that a critical component of the modeling discourse management style "is to lay the foundation of a learning community early and continue to build the community throughout the semester" (p. 53). Desbien notes that some student conversations have extended over an hour in length as students have wrestled with physics concepts and representational tools. Facilitating a classroom discussion of such length (or any length) requires specific strategies, and research discussing these strategies and the tensions experienced while facilitating discourse is discussed in the following section.

Classroom Discourse in Practice

Facilitating discourse. Facilitating discourse includes understanding the effects of what a teacher says, acknowledging the role of silence, being comfortable with incorporating student questions, and recognizing the value of experiencing tension; each of these will be discussed in turn. Moje (1995) examined the effects of what a teacher says in the science classroom; her case study of a high school chemistry classroom revealed that the teacher consistently referred to science as a discipline "that required organization, accuracy, and precision" (p. 355). The teacher also talked about science "in a way that distinguished science from other disciplines" (p. 355), and she used language such as personal pronouns in a way that identified both her and her students as members of the science community. The effects on students ranged from inclusion to alienation "simply as a result of certain ways of using language" (p.368).

Silence is often a component of classroom discourse. In his exploration of variation in classroom conversations, Alpert (1987) observed discussions he categorized as active, silent, and controlled. Silent discussions were named as such because "students' silence stood out as their main mode of classroom behavior" (p. 32), and the behavior reflected "a student's lack of interest and was a sign of passive resistance" (p. 33). Even active discussions contained moments of silence because "active discussions resembled conversations in everyday life" (p. 38), and participants often need time to make sense of the contributions that have been made. Brandenburg (2008) states that silence does not mean students are not learning; and speaking does not always suggest that students are learning. When exploring why her students were silent, Brandenburg's study (2008) identified fear, the pace of the conversation, waiting, contemplation, and having nothing to contribute as the most common reasons for students being silent. Sometimes it is important for teachers to provide silence; for instance, van Zee and Minstrell (1997b) reported how allowing moments of silence provided "the opportunity and time to process the main point of the lesson" (p. 215). Moreover, in her teacher preparation course, van Zee (2000) analyzed a discussion in which "students generate comments and questions while inquiring about a topic without much intervention from a teacher" (p. 117). The instructor identified her own behaviors of 'practicing quietness.' She used wait time to allow room for processing and student responses, she demonstrated 'attentive silence' in listening to other people's thinking without interrupting them, and she displayed ‘reticence’ by “withholding one’s own opinions and understandings while assisting others in expressing theirs” (p. 131). Van Manen (1990) discusses how silent spaces can also be interpreted as spaces that are actively constructed and representing more than an emptiness of speaking, a “literal silence.”

In addition to understanding silence, an instructor’s welcoming and handling of student questions is paramount in facilitating discourse. Van Zee, Iwasyk, Kurose, Simpson, and Wild (2001) reported findings from case studies that determined the contexts in which students asked questions. Their research found that student questions were associated with a certain level of comfort; students asked questions when they were invited to do so, when they had conversations about very familiar contexts, when they felt they were in a comfortable discourse environment, and when they worked together in small groups without the teacher present. To incorporate student questions, van Zee and Minstrell’s (1997a) focused on the questioning strategy called the reflective toss sequence; this move consists of a student statement, teacher question, and additional student statements. Their analysis of these reflective tosses resulted in the emergence of the action plans, goals, or beliefs of (1) engage everyone in considering a method unexpectedly proposed by a student, (2) begin the refinement process by clarifying a method discussed earlier (3) evaluate an alternative method. By asking questions “that can help clarify meanings, examine a variety of views, and monitor the discussion process, teachers and students can work together to refine their understandings toward more scientific conceptions” (p. 259). In another example, when van Zee and Minstrell (1997b) began a discussion, all student responses were presented “as respectable possibilities that merited serious consideration" (p. 216). Throughout the discussion, almost all of the instructor's responses "were contingent responses, comments and questions that were directly related to the prior student utterance" (p. 214). In addition, by using the reflective toss, responsibility was directed back to the student and other members of the class" (p. 215). Finally, the instructor used polling to encourage all the students "to process the discussion sufficiently to make a commitment to a particular point of view" (p. 217).

Until students can commit to the scientific point of view, the instructor will inevitably experience tension when trying to address student contributions inconsistent with the scientific view. Hammer (1995) examined such tension experienced by teachers when facilitating student discussion; specifically, there was inherent tension because students were actively participating, but they were "invoking misleading data, reasoning based on inappropriate assumptions, and drawing incorrect conclusions" (p. 403). However, he observed students bringing in prior knowledge and conducting thought experiments, and an increasing awareness of each other's ideas. Scott, Mortimer, and Aguiar (2006) explored a similar tension; once the student views are known, the teacher faces the challenge of what to do next - how to move toward the accepted scientific point of view. This tension is ever present between "developing the dialogic approach of encouraging students to make their views explicit on the one hand, and focusing more authoritatively on the accepted scientific point of view, on the other" (p. 616). The tension "requires resolution through authoritative guidance by the teacher" (p. 623). Interestingly, authoritative statements by the teacher "demand dialogic exploration by students" (p. 623) as they also experience tension. Overall, then, the facilitation of discourse requires skill and often includes tensions when considering the scaffolding needed during discourse facilitation.

Scaffolding. As first described by Wood, Bruner, and Ross (1976), scaffolding is the mindful intervention of an adult that enables a novice to solve a problem or carry out a task which would not be possible if the learner were left unassisted. Wood, Bruner, and Ross discussed steps in the scaffolding process such as recruiting the student to the task, simplifying the task by limiting the degrees of freedom, maintaining direction in the task, marking critical features of the task as it progresses, and using demonstration to assist the learner. In addition to the content-based interventions, the researchers also described how scaffolding involves the effort of minimizing the learner's frustration during the process. As the scaffolding is implemented, the expert is always comparing how the task could be completed with how the student is performing at that point, and it is the comparison of these two theories that informs the expert which feedback will be "more appropriate for *this* tutee in *this* task at *this* point in the task mastery" (Wood, Bruner & Ross, 1976, p. 97).

The metaphor of scaffolding has been deepened and broadened since its original introduction. Scaffolding has been clearly linked to Vygotsky's developmental notion of the zone of proximal development (ZPD); the ZPD is the range of activity that can be accomplished under guidance but not independently. Similarly, Stone (1998) discussed how both the learning of new concepts and procedures and genuine conceptual reorganization results from scaffolded interactions. Palincsar (1998) explored the importance of the student's understanding, adding that is essential that we understand the child's definition of the task in order to fine-tune the assistance that is provided. Guzdial (1994) discussed how a critical component of scaffolding is *fading*; as the learning progression continues, if the scaffolding is successful, students will learn to achieve the action or goal without scaffolding. In addition, Williams and Baxter (1996) distinguished the scaffolding of content ideas from social scaffolding, the scaffolding of norms for social behavior and expectations regarding discourse. Moreover, Rogoff (1990) raised a concern about the original conception of scaffolding related to its focus on adults as the agents for instilling new skills and understanding; peers provide expertise in today's collaborative classrooms. The idea of scaffolding is important in facilitating discourse in the classroom. Another issue teachers encounter when considering discourse modes is how (or whether) discourse should be assessed; the next section examines research on assessing discourse.

Assessing discourse. Assessing discourse is complex. As an instructor there is a temptation to assess students on the correctness of their contributions; however, in assessing student participation, Klaassen and Lijnse (1996) advised caution in labeling student comments as misconceptions. Consistent with the ideas of social semiotics, the source of the differences between the student's concept and the scientifically accepted one could be from the student "attaching a different meaning to the expression" (p.127). Leander and Brown (1999) presented a framework to describe what they called the dynamic dance of (in)stability in student interactions, as students wrestled with the discourse of the institution, the authority, and other students in the interaction. Students do wrestle with appropriating scientific discourse; Harlow and Otero (2005) examined the usage of scientific vocabulary, and observed that students tend to pick up the use of scientific language implicitly from the teacher. However, the students' use of the scientific language was not always correct when placed in a broader context, suggesting that the correct use of science terms is not necessarily evidence for conceptual understanding.

In order to avoid assessing content and to focus on how content is constructed and evaluated by peers, Etkina et al. (2006) first identified *scientific abilities*, "some of the most important procedures, processes, and methods that scientists use when constructing knowledge and when solving experimental problems" (p. 1). These scientific abilities include (A) the ability to represent physical processes in multiple ways; (B) the ability to devise and test a qualitative explanation or quantitative relationship; (C) the ability to modify a qualitative explanation or quantitative relationship; (D) the ability to design an experimental investigation; (E) the ability to collect and analyze data; (F) the ability to evaluate experimental predictions and outcomes, conceptual claims, problem solutions, and models, and (G) the ability to communicate. They then developed tasks and formative assessment rubrics to measure the students' competency in these scientific abilities. These rubrics contained descriptions of four levels of performance, (0 – Missing, 1 – Inadequate, 2 – Needs improvement, and 3 – Adequate) with descriptors at each level. They are used by students to self-assess their progress (including their ability to communicate). Etkina, Karelina, and Ruibal-Villasenor (2008) used these rubrics to measure students' acquisition of complex scientific abilities such as making decisions based on evidence and using evidence to consider alternative explanations, behaviors consistent with those engaging in scientific argumentation. While these rubrics were originally created for assessing student writing, Brookes and Lin (2010) reiterated that there are "a shared set of socially transmitted and negotiated 'meta-discursive' epistemic rules and epistemic activities that physicists engage in" (p.5) and used the scientific abilities rubrics to assess student discourse during whole class discussions. For example, invoking some of the scientific abilities in the rubrics, the instructor would pose questions such as "'what were your assumptions?' 'How would you evaluate student X's result?' 'Is there another group who has an alternative hypothesis to explain these data?' and so on" and so forth" (Brookes and Lin, 2010, p. 6). Assessing discourse, then, like facilitating discourse, includes levels of complexity much deeper than those encountered when facilitating triadic dialogue; such complexity can hinder any teacher's attempt to change his or her practice. The final section examines some challenges teachers face moving toward a more dialogic classroom.

Teacher willingness to change. Although the incorporation of discourse is an important aspect of the discursive nature of science, the process of teachers modifying their practice is not one that happens easily. For example, Driver, Newton, Osborne (2000) describe how argumentation is necessary to give fair account of the social nature of science, but the lack of teacher's skills in organizing argumentative discourse presents considerable challenges to implementing such discourse. Likewise, in their analysis of student improvement in argumentation Osborne, Erduran, and Simon (2004) recognize teacher fears in promoting argumentation in class because of a concern for lack of control, so overcoming fear would need to be addressed. Similarly, Scott, Mortimer, and Aguiar (2006) acknowledge when considering incorporating student views in a dialogic approach, teachers "must know how to respond to those everyday ideas in attempting to move along the students' ways of talking and thinking" (p. 623), and this faculty would require considerable training and support. Practically, teachers are also reluctant to incorporate some discourse genres simply because of time. As Scott, Mortimer, & Aguiar (2006) recognize, when under pressure to cover content, teachers do not always feel that they can "afford to spend lots of time in listening to what their students have to say" (p. 624). Martin and Hand (2009) add that experienced teachers have developed strategies they considered successful, and these strategies have become "entrenched as automatic ways of operating" (p. 35); in fact, even with consistent interactions of professional development it took about 18 months for the teacher's practice to change. Overall, then, there are challenges that need to be addressed to provide the space for varied discourse in science classrooms. By closely examining one teacher's experience facilitating discourse, this study hopes to provide some substantive points to consider for any teacher wishing to improve his or her effectiveness contributing to meaning making in his or her classroom.

To summarize, discourse is the foundation for schooling; learning occurs as students and teachers rehearse ideas through talk. Science talk is a specific way of talking about the world, and science teachers are responsible for teaching the social language of science. While the dominant form of classroom discourse has been triadic dialogue, efforts at both implementing discourse in an environment promoting exploratory talk or argumentation and curricular reform efforts in physics have altered the discourse paradigm in many classrooms. Facilitating such discourse, though, requires skill and presents some challenges. The next chapter focuses on the research methods of this study, a self-study of one teacher’s experience facilitating group discourse in the physics classroom.

Chapter 3 : Research Methods

In this chapter I present the research methods used in this study. As context for the study, I begin by summarizing Modeling Physics, the instructional approach used in my high school classroom. Second, I describe the classroom setting and the participants. Third, I present the methodology for the study and the data that was collected for this study. Fourth, I describe the two-stage analysis of the data, including the analytical framework followed by a brief description of discourse analysis. Finally, I discuss limitations of this research.

A Synopsis of Modeling Instruction

The instructional approach used in my physics classroom draws upon modeling theory in physics instruction (Hestenes, 1987; Wells, 1987; Hestenes, 1996), and it attempts to reduce the fragmentation that typically occurs in an introductory physics class by organizing the content around several mathematical models. For each instructional unit, the design, development, and deployment of a conceptual model forms the basis for instruction, and each of these three stages of the modeling cycle (design, development, and deployment) are shown in Figure 3.1 and will be discussed in turn.

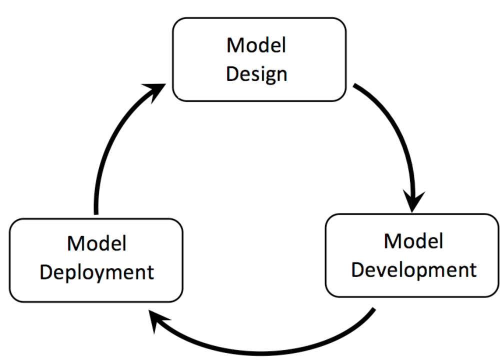


Figure 3.1. Modeling Cycle as applied in this physics classroom.

Model Design Phase. Each unit begins with the model design stage, which often involves a short demonstration where the instructor asks students to make observations about an observed phenomenon. From this student-generated list of observations, students are asked to identify what aspects of the system could be measured and how the behavior of objects in the system could be changed. Building on this activity, the instructor poses a laboratory research question, and after some introductory experimental design remarks, students then work in small groups to conduct an experiment to address the research question. The instructor assigns a slight modification to each group to differentiate one group's experiment from another; for example, when studying the accelerated motion of a cart down a ramp, a modification might involve investigating a different variable such as the angle of the ramp or the mass of the cart. As groups conduct the experiment, they discuss how to make measurements and how to consider their data, exercises that are a necessary part of empirical work. Student groups then analyze their findings (often using graphical analysis software), and once they have identified a relationship that addresses the research question, they create a whiteboard display of their graphical analysis. Because this laboratory activity will eventually establish the model for this unit, it is often referred to as the paradigm lab for the unit.

Model Development Phase. At this point, the model development stage begins, and the class convenes in a large group similar to those described in Modeling Discourse Management (Desbien, 2002). In this mode the student groups are arranged in a circle so that the group whiteboards are visible to all other participants. This gathering is called a whiteboard meeting (or board meeting), and in this meeting the instructor facilitates a large group discussion in which students discuss how the group's findings are similar to one another, how they are different from one another, and what relationships appear in the data. Behavioral norms and expectations are identified prior to the discussion, because in the conversation, students are encouraged to speak without needing to raise their hands, to listen to their peers, and to provide arguments supporting or challenging conceptual ideas. Through facilitation, the conversation eventually leads to a specific relationship between the variables being studied, including the interpretation of slopes and meaning of vertical intercepts displayed in the student graphs. This relationship becomes the conceptual model for this unit.

Model Deployment Phase. After the model has been developed, students engage in the model deployment stage of the modeling cycle. In this stage, the students work in groups on tasks that apply the model to various situations described in worksheets or in classroom problems. To discuss how students applied the model in their circumstances, groups will often be assigned a problem to write up on a whiteboard and present the solution to the class for peer review. Occasionally, the students may engage in a graded discussion pertaining to the topic. Each unit culminates with a lab practicum, an application of the model to a real situation whose outcome can be observed by the students. For instance, in the constant velocity unit, students are asked to determine where two different toy buggies will collide when facing each other and released simultaneously from a specified separation distance.

The instructional units follow this general sequence, but as units progress, a new model might rely on the incorporation of models developed in previous units. For example, when learning about projectile motion, it is helpful to model this parabolic motion as two independent motions happening simultaneously, and as a result students will need to incorporate both constant velocity and uniform accelerated motion models in addition to balanced force and unbalanced force models. Overall, the models become the foundation for instruction throughout the course, but each of the stages of the modeling cycle − the design, development, and deployment − all depend on student discourse. It was the recognition of the need to facilitate this discourse that motivated this study.

Participants and Setting

University High School is a suburban public high school outside of a mid-sized Midwestern city in the United States, and in this school district of about 3200 students, the high school has approximately 1200 students in grades 9-12. The high school student body consists of about 93% White students with the remaining seven percent composed of African American, Asian American, Hispanic, and Native American students. Economically, the district has about 8% free and reduced price lunch, and academically, the high school's graduation rate is over 98% with about 90% pursuing college as a post-secondary path. The high school has a reputation for strong academic performance, and its standardized test scores are consistently some of the highest in the state. The school has four levels of physics: conceptual, general, calculus-based Advanced Placement, and a dual-enrollment course with a nearby university. Each class period meets for 54 minutes, five days each week.

Physics is an elective courses at University High School, so all students have self-selected to take physics. More than half of each graduating class elects to complete a physics course. There were 31 students in the section of high school general physics class being studied, with one student in the 11^{th} grade and the remaining students in 12^{th} grade. There were 16 female and 15 male students in the course, and out of the 31 students enrolled three were three students of color. Economic information for the enrolled students was not available.

Researcher Background

I have been teaching at this school for eight years, and I taught for nine previous years at urban private schools. Although I have been teaching physics for almost my entire career, I actually received my undergraduate degree in mechanical engineering. I pursued teacher licensure in physics through a post-baccalaureate teacher certification program, and also received a Master's degree in secondary science education. However, through this coursework, I never received training on how to promote or facilitate discourse in the science classroom. Nevertheless, I have participated in some meaningful professional development opportunities in which I have experienced scientific discourse as a student, most notably the University of Washington Physics Education Group's *Summer Institute for In-service Teachers* and Arizona State University's *Modeling Physics Workshop*. Through these opportunities I have witnessed how such discourse has been facilitated in both small and large group settings, and from these experiences I knew I wanted to closely examine the discourse I facilitate in my classroom.

Methodology

This research is an example of a self-study in which one documents and interprets data from one's own classroom in order to generate knowledge of teaching practices from a practitioner's perspective (Cochran-Smith and Lytle, 1993). For this study, I analyzed two formats of large group discussion in my physics classroom; these speech genres "are related to the social and institutional place where the discourse is produced" (Buty and Mortimer, p. 1640). The first genre was the board meeting, the large circle discussion of the paradigm lab discussed as part of the model development stage of the modeling cycle in the section above. The second genre was the graded class discussion. Although this activity is not prescribed specifically by modeling instruction, I occasionally supplemented my physics classes with this genre because as an additional opportunity for students to engage in discussion during the model deployment stage of the modeling cycle. In this genre, a problem was presented to the class and students had the chance to consider the solution and discuss it in small groups. Then we convened as a large group and attempted to determine a solution to the problem through large group discussion. I facilitated the discussion as we worked toward a solution to the problem.

Data Collection

Multiple data sources were used in this study. Digital audio recordings were made of all large group discussions from the middle of September to the middle of May over the academic year 2012-2013. Specifically, nine board meetings were recorded and two graded discussions were recorded. In addition, video recordings were made of six of the board meetings and both of the graded discussions, but because the students and teacher were arranged in a circle for the board meetings, capturing video for those lessons was difficult. A timeline for the dates that the lessons were conducted is shown in Table 3.1, identifying those discussions included in this research.

Table 3.1.
Group discussion data collection.

Date	*Group Discussion*	*Included in Study*	*Audio Recording*	*Video recording*
Sept. 17	Board Meeting 1 - Unit 2, Constant Velocity Motion	X	X	X
Oct. 4	Board Meeting 2 - Unit 3, Accelerated Motion		X	X
Oct. 5	Board Meeting 3a - Unit 3, Accelerated Motion, Part 2		X	X
Oct. 5	Board Meeting 3b - Unit 3, Accelerated Motion, Part 3		X	X
Oct. 16	Graded Discussion 1 - Cart on Ramp	X	X	X
Nov. 26	Board Meeting 4 - Unit 4, Force of Weight		X	X
Dec. 18	Board Meeting 5 - Unit 5, Newton's Second Law	X	X	X
Jan. 11	Board Meeting 6 - Unit 6, Projectile Motion	X	X	
Feb. 11	Board Meeting 7 - Unit 7, Hooke's Law		X	X
Feb. 15	Board Meeting 8 - Unit 8, Kinetic Energy		X	
Feb. 21	Board Meeting 9 - Unit 8, Gravitational Potential Energy		X	
May 9	Graded Discussion 2 - Electric Circuits	X	X	X

In addition, I kept a journal to reflect on my experiences on the days I recorded discussions, with the mindset that post-reflection helps make theory meaningful in its connection to the researcher experience (Ballenger, 1999). Overall, the intent of these sources was to provide the basis for a rich description of the discourse genres I facilitated in my physics class.

Data Selection

Although I taught both dual-enrollment college level physics and general physics, data was only collected in the two sections of general physics classes. I was interested in analyzing the discourse facilitation of general physics students; those students in advanced classes tend to demonstrate higher-level reasoning and argumentation skills

(Means & Voss, 1996). For several reasons, data was only analyzed for the second period; it had a larger class size (31 students compared to the 24), and it had a smaller percentage of students currently enrolled in calculus (10% compared to the 50% in period 4). The math course enrollment created a de facto tracking effect for students in that later physics class. Consequently, it was felt that period two presented the greatest opportunity for contributing to the literature through analyzing discourse facilitation.

The semester ended in the middle of January, so as Table 3.1 shows, almost all data was collected during the first semester. All the board meetings selected for analysis and the first of the two graded discussions occurred during the first semester. This semester recognition is important because the class composition did change at the semester break; on their accord, three students transferred from general physics to conceptual physics as the mathematics in general physics was too challenging. Two other students dropped out of physics to pursue other interests.

Almost all of the large group discussions were recorded knowing that specific examples would be selected for analysis later. From the board meeting discussions, eleven recordings were made and three board meetings from the first semester of physics were selected for analysis; although some second semester board meetings contained interesting discussion, I decided to prioritize consistency of the class composition when possible. I selected the first board meeting that was conducted because I wanted to explore my introduction to the genre and examine how students engaged in this first meeting. The second board meeting I analyzed was the discussion from Unit 5, the introduction to Newton’s second law, and I selected this meeting because the scientific content of the inverse relationship between acceleration and mass required some manipulation of the entire class's data to eventually develop the model. The third board meeting that I analyzed was the last board meeting of the first semester in which we developed the model for projectile motion. This discussion was selected because of the change in pre-discussion routine in which I gave students to share ideas in small groups before convening the large group discussion.

For the second discourse genre, I recorded the two graded discussions that I conducted during the academic year (one each semester). The first graded discussion was based on students predicting position versus time and velocity versus time graphs for a cart traveling up and down a ramp, and I was interested in exploring the extent to which I provided space for students to share their ideas as I facilitated the conversation. The second graded discussion concerned students ranking portions of electric circuits based on the total resistance of the circuit portion, and I was interested in analyzing that discussion because of the struggle that students typically experienced in wrestling with the ideas involved in the task.

Overall, each of the five discussions was unique, and they were selected because each of them could provide something meaningful for the practice of discourse facilitation. This study is not action research; specific premeditated goals and plans of action were not determined beforehand. Rather, this is an example of my attempt to be a reflective practitioner (Schön, 1983) and examine the opportunities for growth that the differences in these examples can provide.

Analytical Frameworks

This research is guided by the following research questions:

- How does my facilitation of classroom discourse contribute to meaning making in the high school Modeling Physics classroom?
- What tensions do I experience in the facilitation of this discourse?

To address these questions, each of the lessons in this study was analyzed using a two-stage process; the first stage was the application of the analytical framework developed by Mortimer and Scott (2003) designed to explore science lesson interactions, and the second stage employed a discourse analysis for key moments in my facilitation of the discourse. Both of those processes will be described in turn. Each of these analytical processes are described in details in the following section.

Interaction Framework. The first stage of my analysis utilized a framework created by Mortimer and Scott (2003) depicted in Figure 3.1. This framework highlights the focus of the lesson, the approach used for interactions, and the actions of the teacher, and specifically incorporates the following five aspects of analysis: (1) Teaching purposes, (2) Content, (3) Communicative approach, (4) Patterns of discourse, and (5) Teacher interventions.

	ASPECT OF ANALYSIS	
FOCUS	**1** Teaching purposes	**2** Content
APPROACH	**3** Communicative Approach	
ACTION	**4** Patterns of discourse	**5** Teacher interventions

Figure 3.2. The analytical framework used for analysis (Mortimer & Scott, 2003).

Teaching purpose. The first aspect of Mortimer and Scotts' framework considers the teaching purposes of the lesson by asking what purpose is being served (in regard to the science) in the lesson. For example, the teaching purpose may consider whether the lesson is helping to open up a problem, is exploring and working on student ideas, or is helping to develop a student understanding consistent with the scientifically accepted view (what Mortimer and Scott call developing the *scientific story*). Any statements that were made at the beginning of a discussion to set the stage, or any clarifying remarks that were made to help students better understand the task were coded as *opening up the problem*. Statements in which students shared their initial ideas and in which students asked for clarification of those ideas were coded as *exploring student ideas*. When I made comments that introduced the scientifically accepted view, or if I emphasized a students' contribution that was consistent with the scientific view, the data was coded as *introducing the scientific story*. Once the scientific story had been introduced, any questions that were posed, reiterations made, or clarifications given were coded as *guiding students to support internalization*. It is worth noting that in the midst of a large group discussion it is difficult to assess whether individual students have authentically internalized the scientific story; thus the code is aptly labeled as *supporting* internalization of the scientific view. Finally, any statements that were made to extend or apply the scientific the scientific view were coded as *guiding students to apply the scientific view*.

Lesson Content. The second aspect of analysis examines the content of the lesson by considering the nature of the content knowledge that students and teacher talk about during the lesson. In the discussion samples, the social language (Bakhtin, 1978) of the interaction was examined, and I identified it as belonging to the everyday social language or the scientific social language. Statements in which students included scientific vocabulary (such as slope, intercept, correlation, velocity, etc.) that had been introduced in class were coded as the scientific social language. While some of these terms have been used in math classes and would seem familiar, they would not make up the content of adolescent conversations in a social context. Similarly, words like *acceleration* that are often in everyday use but had been formally defined in the science class were coded as the scientific social language. Occasionally, students made contributions consistent with the scientific view that indicated prior scientific knowledge with the topic, and such contributions were also coded as the scientific social language. All other statements were coded as the everyday social language.

After identifying the social language, the statement was examined to see if it was a description, an explanation, or a generalization. In addition, each of these three types of language were further classified as empirical or theoretical. For instance, statements that provided "an account of the phenomenon in terms of the observable features" (Mortimer and Scott, 2003, p. 31) were coded as empirical, while statements that went "beyond the phenomenon by drawing on theoretical entities that are not observable in the phenomenon itself" (p. 31) were coded as theoretical. Any statements that students made attempting to "establish relationships between physical phenomena and concepts, using some form of model or mechanism to account for a specific phenomenon" (p. 31) were coded as explanations, and those explanations were also identified as empirical or theoretical. Finally, any statements that were “not limited to a particular phenomenon, but express a general property of scientific entities, matter, or classes of phenomena” (p. 32) were coded as generalizations, and these too could also be empirical or theoretical.

Communicative Approach. The third aspect of analysis in the framework analyzes the communicative approach between the teacher and students and considers how the teacher addresses the diversity of ideas present in the class during a particular phase of the lesson. In analyzing the data, the communicative approach was first described as being either dialogic or authoritative; talk is considered dialogic “is the fact that different ideas are acknowledged, rather than whether it is produced by a group of people or by a single individual” (Buty and Mortimer, p. 1639). In an authoritative approach the attention is focused on just one point of view, only one voice is heard, and there is no exploration of ideas. In addition, the communicative approach considered whether the interaction was interactive; that is, an interactive approach allows for the participation of other people while a non-interactive excludes the participation of other people. These two dimensions work together to form the four communicative approaches shown in Figure 3.3.

	INTERACTIVE	NON-INTERACTIVE
DIALOGIC	**A** Interactive/ dialogic	**B** Non-interactive/ dialogic
AUTHORITATIVE	**C** Interactive/ authoritative	**D** Non-interactive/ authoritative

Figure 3.3. Four classes of communicative approach.

Patterns of Discourse. The fourth aspect of analysis in the Mortimer and Scott framework examines the patterns of discourse between the teacher and students. Specifically, this aspect considers the interaction patterns that develop as the teacher and students take turns in classroom talk. When coding the data, portions of the discussion were separated into stanzas of groups of idea units (or clauses) that focused on a particular topic (Gee, 2011). The stanzas might have been coded as the traditional triadic dialogue of teacher *initiation*→ student *response* → teacher *evaluation* (the *I-R-E* sequence), or if I provided *feedback* or a non-evaluative follow-up, the interaction pattern was coded as an *I-R-F* pattern. Encouraging student elaboration with successive follow-up moves could result in an *I-R-F-R-F* sequence or an extended chain (*I-R-F-R-F…*). The possibilities for interaction patterns are varied.

Teacher Interventions. The fifth and final aspect of the framework considers the teacher interventions that occur at various points in the lesson to develop the scientific story and make it available to all the students. Interventions may include the shaping of ideas, the selecting of ideas or marking key ideas, sharing ideas, or checking student understanding/ reviewing. Each of these interventions happens because of a teacher action; specifically, if I focused attention on a particular student response or if I overlooked another student's response, the contribution was coded as selecting ideas. Similarly, if I repeated what a student said, my statement was coded as marking key ideas. A summary of this and all coding keywords is shown in Table 3.2.

Table 3.2.
Coding hierarchy using Mortimer and Scott's (2003) analytical framework.

Framework Aspect		Keyword		
Teaching Purposes	*Opening up the Problem*			
	Exploring Student Views			
	Introducing the Scientific Story			
	Guiding Students to Support Internalization			
	Guiding Students to Apply Scientific View			
	Maintaining the Development of the Scientific Story			
Content of Interactions	*Social Language*	*Everyday*		
		Scientific	*Description*	*Empirical*
				Theoretical
			Explanation	*Empirical*
				Theoretical
			Generalization	*Empirical*
				Theoretical
Communicative Approach	*Interactive/Dialogic*			
	Interactive/Authoritative			
	Non-interactive/Dialogic			
	Non-interactive/Authoritative			
Patterns of Discourse	*I-R-E (Triadic Dialogue)*			
	I-R-F			
	I-R-F-R-F (Chain)			
	I-R-F-R-F-... (Extended Chain)			
	IS-RT-FS (Student initiated)			
	...			
Teacher Interventions	*Shaping Ideas*			
	Selecting Ideas			
	Marking Key Ideas			
	Checking Student Understanding			
	Reviewing			

Together these five aspects of analysis provide "an *integrated* analysis of how classroom talk contributes to meaning making in science lessons" (Mortimer and Scott, 2003, p. 46), and they provide a framework for meaningful examination of the lessons and discourse included in this study. Specifically, Mortimer and Scott's framework addresses my first research question about the presence of dialogic discourse in Modeling Physics instruction while providing contextual information about the lesson.

Transana. The coding of for the analytical framework was performed using Transana software. Audio and video files were imported into the software, and for the video files Tansana extracted .wav files. Transcripts were also imported into the software, and then the existing keywords or codes from the analytical framework were entered into the software. Time codes were placed into the transcripts that linked the audio files to the written text, so statements selected in the transcript could be immediately heard in the recordings. This study applied the language of Transana in the coding process; specifically, codes in this study are referred to as "keywords," and using the Mortimer and Scott (2003) framework, keywords included teaching purposes, patterns of discourse, and all other aspects of the framework. As a result, the keywords in this study were not single words, but consisted of idea units in one phrase or even an interaction sequence between participants that included multiple phrases. The output from Transana was maps of the coding distributions called keyword maps, and they appeared as representations of the discussion for the various aspects of the framework. A sample keyword map is shown in Figure 3.4.

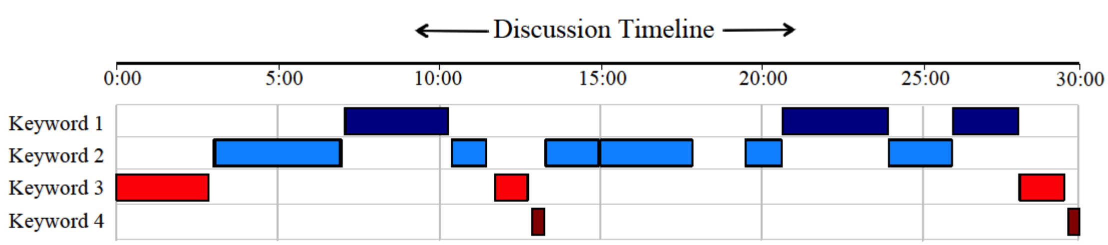


Figure 3.4. Sample keyword map output from Transana

The keyword map shows the presence of the statements or contributions corresponding to the codes or keywords used in the analysis of the conversation. The discussion progresses from left to right along the discussion timeline (graduated in five minute intervals), so the position of the keyword bands can provide an account of the flow of the discussion according to various aspects of the analytical framework.

The use of Transana to generate and the subsequent analysis of the keyword maps served as the primary methodology to address my first research question, how my facilitation of classroom discourse contributed to meaning making in the high school Modeling Physics classroom. However, to address my second research question, identifying the tensions I experienced in the facilitation of this discourse – I engaged in a second stage of analysis. This second stage utilized the approach of discourse analysis (Gee, 2011), and is described in the following section.

Discourse Analysis. Discourse analysis is the study of language at use in the world to both say things and to do things (Gee, 2011). While the idea of social language discussed earlier described certain ways of speaking that are recognizable by particular social groups, Gee uses the concept of Discourse (big "D") to integrate language with ways of acting, being, interacting with others, believing, and using various tools in specific environments. This study considers the Discourse of being a physics student in my high school classroom; it examines how I did and did not introduce students explicitly to the ways of being a participant in board meeting and graded group discussions. I described the norms and expectations for each speech genre discussed here, and those comments were intended to introduce this Discourse to the students.

In addition to Gee's (2011) Discourse tool, there were other tools that informed the analysis I present here. Specifically, I incorporated the examination of some grammatical features. For instance, in considering the sentence mode I am able to understand the positioning of participants in the conversation. Participants acting as information providers did so using declarative statements, while participants seeking information constructed interrogative statements. Imperative statements represented power differential in that one participant was directing another person to act in a particular manner.

Other grammatical features were incorporated in this research. For example, I considered the role of connectors, such as *so* or *because*. These conjunctions serve as a means to connect one clause to another, and in language they can indicate the presence of assumptions or conclusions. I also looked at the use of pronouns, especially the personal pronouns *we* and *you*; the use of these pronouns can create a sense of collectivity or isolation depending on the context.

There were other tools proposed by Gee (2011) that informed this analysis. For instance, there was the *Why This Way and Not That Way Tool*; this encouraged me to consider why I said things in the way that I did, and not in some other way. The *Fill In Tool* encouraged me to consider what was said and the context of what was said to determine what was missing from the exchange; what could have been included to achieve greater clarity.

My approach of using elements of discourse analysis in this research involved looking at what struck me in the transcripts and recordings from the group discussions. With each discussion, I first considered my intentions with that discussion, and then I attempted to compare those intentions with what seemed to really happen. I was drawn to moments that were difficult, and those moments usually reflected some sense of tension or discomfort. While a teacher likely experiences myriad tensions every class period, it was those larger incidents of discomfort that I explored in this study with my research question. Those were the incidents I analyzed beyond the analytical framework by Mortimer and Scott (2003).

These incidents are not collected in one section of the paper; they are located within the section of the analytical framework application that was most pertinent to their situation. In these sections, the text is somewhat more narrative in structure than in the application of the Mortimer and Scott (2003) framework, but the analytical framework still served as the guiding architecture for the discussion.

Limitations of the Study

This research, like all research, has inherent limitations. As described in sociocultural theory, the research presented here can only be understood in the context of the specific location, in this case, a suburban, middle class community in the Midwestern United States in the early part of the 21st century. This research is an honest effort to understand the interactions in my classroom situated in that context. In addition, the tools used for thinking in this classroom “originate in human culture” (Mortimer and Scott, 2003, p. 10), and specifically in the culture in which this classroom is situated; the attempt to convey the classroom culture has been more successful at some moments than others, but in any event this research is one teacher’s description of his experience, at one school over the course of one school year in time.

Admittedly, the demographics of this student population do not mirror the general demographics of the United States; the school’s poverty level is considerably lower than many other high schools, and its cultural demographics are quite homogeneous. The school's strong academic performance is exemplified on a regular basis: most students attend school daily, most students do their homework, and most students come to class with the materials they need. So even though this research is being conducted with the general physics class, the students still generally demonstrate strong academic performance. Moreover, the reality that this course is an elective results in most students having some inherent desire to be there. And as I described earlier, those students who do not feel successful have the option of changing their schedule to a different physics course (or a different course altogether); other teachers of courses required for graduation do not have this same situation.

As the instructor, my experience and my interpretation of that experience is shaped by my identity as an educated white, middle class, heterosexual, male living in the United States. In appearance, I look like I could be in the family of many of the students I teach. Because of the nature of this research and the participants in this research, there is no expectation that the findings of this study will transfer directly to another classroom or even be generalizable to all physics teachers using modeling instruction; what I do hope is that something from this study resonates with other teachers interested in facilitating scientific discourse in their classrooms with the intention of helping students learn.

In the next chapter I discuss the findings from applying the analytical framework to the two speech genres of large group discussions analyzed in this study. First I discuss three board meetings that occurred in the first semester of the high school physics class. Then I discuss the two graded discussions that were conducted during the year.

Chapter 4 : Discussion of Findings

In this chapter I present and discuss the research findings for the whiteboard conversations and graded discussions. The three board meeting conversations are analyzed in turn. Each discussion begins with an introduction to the respective physics lesson, and then the keyword maps for each aspect of the analytical framework are introduced and discussed by first comparing my intent of the lesson with how it actually unfolded and then by discussing points to consider. Next, I present and discuss the research findings for the two graded conversations; because of the lessons' similar structure the two graded discussions are presented together. After introducing the physics topics involved in the graded discussion lessons, I discuss the two conversations according to each aspect of the analytical framework. The two lessons' keyword maps for each aspect of the analytical framework are introduced and discussed by first comparing my intent of the lesson with how it actually unfolded.

Board meeting 1: Constant Velocity Motion

The first board meeting was selected for analysis because I wanted to examine my introduction to this speech genre and examine how students became acclimated to the discussion process. This conversation followed a laboratory experiment in which students explored constant velocity motion. Student groups collected position and time data for two different configurations of the motion of battery-powered toy buggies. Each group had the same first configuration with the buggy starting at the origin at time $t = 0$ and traveling in the positive direction. To create distinct outcomes for each group, each group's second configuration had a modified starting position, speed, or direction in which the buggy traveled. Students analyzed their data for both configurations using Logger Pro software to generate graphs and the corresponding equations for the graphs' lines of best fit. These findings were written on one whiteboard per group, an important discourse meditational tool in Modeling Instruction emphasized by Wells (1987). The classroom was organized for the white board meeting so that all students could sit in a large circle and see their classmates' whiteboards (Desbien, 2002).

Teaching purposes. In the lesson, I ultimately wanted students to discuss the shape of the plots, the correlation of any linear fit applied to the data, and the meaning and interpretation of the intercept slope of the best fit line. Because the class had just finished worksheets and small group presentations concerning these attributes, I anticipated that the students would have been primed for conversing about these topics in the board meeting, and there would be a clear progression from the opening up of the problem to the exploration of student views to the introduction of the scientific view and its internalization. The keyword map for the first board meeting's teaching purposes is shown in Figure 4.1.

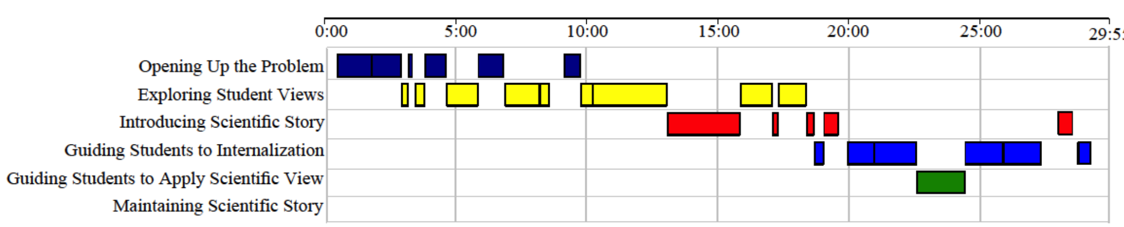


Figure 4.1. Board meeting 1, teaching purposes keyword map.

The first several minutes of the discussion were coded as opening up the problem as I introduced the expectations and norms for the discourse genre. This was the first board meeting for the students, and I began by saying “This is called a board meeting. And it's called that because we use the whiteboards to be our basis for conversation here” (BdMtg 1, 0:00:29). The use of the phrase *board meeting* has a situated meaning within the corporate world; the use of board meeting in that context implies a formal, important event in which selected leaders debate issues and make decisions for the organization they represent. I had hoped that with this population of students whose parents serve on school boards and are immersed in the corporate culture of some multinational corporations the figured world of board meeting might have significance. It is unclear, however, how this phrase would be perceived by students whose families are not participants in such a figured world.

I also posited “the board meetings are actually one of the most different aspects of this course because instead of doing like presentations from our labs, we do these board meetings to actually have an analysis conversation” (BdMtg 1, 0:01:06). By stating that this event is one of the most different aspects of the course, it implied that the course was different from something; however, whether it was different from another high school course, another high school science course, or whether the difference simply lay between events within this course was not clear. More importantly, this quote ended by stating that this conversation is an *analysis* conversation, but I did not provide a description or explanation for what I meant by analysis. Because “analysis conversation” is not a phrase that is typically used in an every day social language, this could have been said differently or elaborated upon to achieve clarity in the minds of the participants.

The opening of the problem also attempted to introduce some procedural norms for the board meeting, this action was intended to introduce the students to the Discourse (Gee, 2011) of being a physics student participating in a board meeting. For example, “It's not you raise your hand and talk, and it's not you just go through your presentation of your information. This is more like a seminar in which you actually just contribute as you make observations that are relevant to the particular situation” (BdMtg 1, 0:01:49). For students who are used to the norm of hand-raising to seek permission to speak in the classroom, this approach diverges from that ingrained tendency. My statement was an explicit attempt to introduce a way of being a participant in a board meeting. Likewise, the way of speaking in these discussions is not just sharing all the content written on the whiteboard, but rather it relies on students making connections between the different student groups’ whiteboard data and voicing those connections in the discussion. However, the use of the word *seminar* might have been troublesome for some students; although some of the students have participated in Socratic seminars in other content area classes, the use of the word might have a different situated meaning than how I assign its meaning in a physics board meeting. If my understanding of seminar had been elaborated upon or if I used another descriptor such as a “talking circle,” I might have been able to construct a more explicit meaning of seminar and students would have had a better understanding of how to be a participant in the board meeting. Moreover, I never introduced the explicit reason of *why* the “speak when moved” norm exists in this speech genre; I understand that this norm minimizes the power differential between student and teacher because the student does not need permission from the teacher to contribute to the discussion. Each student is empowered in his or her contributions, and this freedom to speak emulates the role of peer review in the scientific community. I never stated this to the students; such elaboration of why board meetings are conducted as they are might have helped students embrace the Discourse of being a participant in a board meeting. Finally, as an attempt for the group to take ownership of the conversation, I stated, “I'll throw some questions out there to get us started. But ultimately I want you guys to try to take control of these conversations as much as you can” (BdMtg 1, 0:03:51). While I used the word *control* to signal that they would have authority in the direction of the discussion, I did not elaborate on what that might look like in practice. Specifically, I could have achieved greater clarity by giving an example of how students would demonstrate their control, or I could have also shared how I might minimize my role as discussion controller.

I attempted to scaffold the content of the discussion by saying:

> “We're looking for um things that are meaningful for this lab. And we always start off with how are the whiteboards similar; you know, how are they similar? Look for similarities, and once we've exhausted all of those similarities, we move into how the whiteboards look different and we try to justify those differences, okay?” (BdMtg 1, 0:04:04).

The intention of this statement was to guide students in the content that would make up the discussion; cognizant that the procedures and norms may differ from their experiences of (science? Classroom discussions in general?), my intent was to be explicit about how we begin so that we would successfully arrive at a model for constant velocity motion. Explicitly repeating the content framework of graph similarities first and graph differences second might have helped the students know what to discuss.

The problem continued to be clarified and opened for about the first ten minutes of the discussion as we began to explore student views. For example, Colin stated how "our slopes for the first um, graph seems to be the same or close to it" (BdMtg 1, 0:06:54). This student was able to distinguish the two configurations displayed on each whiteboard and note the similarity of these slopes across all the whiteboards. In addition, I worked on student ideas when Moe said "some people have the same issue as my group, where the correlation was zero" (BdMtg 1, 0:07:26). As this was a computer malfunction that resulted in the correlation being displayed incorrectly, I responded by saying the data "are forming what looks like a relationship. So know that the correlation of zero was an error somewhere on Logger Pro" (BdMtg 1, 0:08:00).

The keyword map shows that student views were explored for the first third of the discussion, and aspects of the scientific view began being introduced 12 minutes into the conversation. For example, as part of a discussion about determining the significance of a calculated vertical intercept from a linear regression fit, we first reasoned that the buggy was at the origin when the clock started and therefore should not result in a vertical intercept on the position versus time graph. Consequently:

SH:	*How can we justify getting rid of it, after we use our reasoning and recognize that it shouldn't be there?*
Colin:	*Is that the 5% rule?*
Teacher:	*The 5% rule. Does that make sense?*

(BdMtg 1, 0:12:37)

Through this interaction the students were reminded of the process of evaluating the vertical intercept of a linear fit. Students first should have used reasoning to recognize that the graph should pass through the origin because the buggy was at the origin was the clock started. However, every group's linear regression resulted in a small intercept value, so then relied on a constructed guideline to assess whether the intercept was a result of measurement uncertainty. In Modeling Instruction, it is referred to as the 5% rule, and it states that if the vertical intercept is less than 5% of the maximum value on the vertical axis, it is possible the value is a result of measurement error. However, the first part of evaluating the intercept is also the conceptual understanding of what the intercept would represent, and in this case it indicates the position of the buggy when the clock started.

Students were guided in supporting the internalization of the scientific view in the last third of the discussion. For instance, after identifying the meaning of the intercept and slope, we explored the second configurations of other groups:

SH:	*Who can identify what their group did differently in the second configuration?* *[10 seconds]*
Gregg:	*Maybe, like, weight was added, because they travel less distance over the same amount of time.*
SH:	*How do you know that?*
Gregg:	*Because they end up on the same 20 second mark, or it appears to, but the distance traveled is less than the second part*
SH:	*So then you describe the motion of the second part as just being...*
Tom:	*Slower.* (BdMtg 1, 0:19:59)

In this example the two students worked to make sense of the other group's data; Gregg made the claim that weight was added, and he used the warrant that the data showed the buggy traveling less distance in the same amount of time. He supported his claim by saying that they ended up at the same time, but one of the buggies traveled less distance. I selected to not focus on the weight claim and rather look at the motion, so in my clarifying statement I asked the students to describe the motion (slower) rather than asking them to explain the different motion (added weight). I avoided this causality because weight was not added, but rather a battery was removed and replaced with a metal slug to make the buggy slower. In this following segment, I was trying to help student recognize that the differences in the motion and the resulting equations had to be consistent with the graphical representation:

SH:	*We already talked about the intercept, they started at four.*
Jason:	*Their second one went faster.*
SH:	*Their second one went faster. And how would we recommend them to tweak their board if they are gonna draw this again in the future.*
Alex:	*Make the line a little bit steeper.*

(BdMtg 1, 0:22:14)

In this example, Jason reminded us of the different motion of the buggies, and after I repeated the answer of the second buggy going faster, and I asked a specific question regarding the modification of the graphs for future depictions of the motion. In addition, After examining one group's equation and noticing algebraic signs of the model, I said, "they have an intercept that's negative. What does that tell us about where their starting position was?" (BdMtg 1, 0:26:07). This question was intended to help students recognize that the sign of the intercept was related to the location of the object when the clock started. If the intercept had a value and a sign that was positive, the object would be located some distance in the positive direction from the origin when the clock started.

This mapping of the discussion's teaching purposes provided me with a representational tool that can inform my instruction, and the analysis provided data that I would not have had otherwise. For example, the following exchange occurred in the beginning of this board meeting, where we were just starting to explore the similarities between the group whiteboards:

Colin: *They are it's just that some of them are graphed differently like um, for their group, their zeros is not like you know where the X and Y meet, it's higher up on the line*

[silence - 36 seconds]

Garrett: *I'm curious on your, ah board of your, your green like how does that work, is, is your Y is your distance then?*

SH: *Is that a similarity or a difference?*

Garrett: *That's a difference.*

SH: *Okay, so let's keep that question, be ready to ask it when we've exhausted similarities okay, Garrett. Others of you might have similar questions about differences we'll certainly have the chance to throw those out there. Is there anything else you wanted to say about similarities?*

(BdMtg 1, 0:05:41)

The episode began with Colin making a declarative statement about something he observed on the whiteboards. He noted that some of the plots are graphed differently, with some of the graphs being higher up on the line. His contribution was not commented on by myself or by any student, so the comment lingered without support or challenge.

From an instructor's perspective, I realized that I never explicitly instructed students to respond to statements made by their peers; my comments centered on instructing students to share observations and ask of questions.

Following Colin's comment, the students were silent, and for 36 seconds, the circle of students sat without making a sound. It was the first period of long silence this group of physics students had experienced together, and it was very tense for me. As the teacher, I was looking around quietly at the whiteboards. I did not look at students' faces, because I did not want to use non-verbal communication to prompt particular students to respond; I had hoped that students would take the initiative to speak. The silence continued, and I became increasingly uncomfortable. I jotted something on my clipboard, and although I don't remember what I wrote, I do remember what I was thinking: the time felt eternal. We had discussed all of the content in class – graph shape, correlations of linear fits, the intercept and its meaning, the slope and its meaning, but the students were not transferring their prior experience to this new speech genre.

Then Garrett spoke up. He was willing to break the silence, and he made an interrogative statement about something he observed. He did not ask me, but rather he asked his peers, the students who owned the work in question. He was seeking information from the only ones who could provide it in that context. However, as I listened to his contribution, and as I began to understand his point, I started forming my response. He was asking about why a green line on one group's plot looked different than the others in the class; he was asking about a difference between this and other whiteboards. It was not a *similarity* among the whiteboards, but rather content that should be reserved for the later portion of the conversation when differences were to be discussed. I was resolved that we discuss similarities first, and then after we had exhausted the similarities we would discuss the differences. I was not prepared to deviate from that plan. He almost did not finish his statement before I responded. I used the interrogative statement, ‘Is that a similarity or difference?’ as a redirection measure, and the audio recording did not indicate gentleness in my statement, but Garrett immediately and humbly responded by stating his response was a difference.

Following Garrett’s response to my question, there was a long pause of 19 seconds, and later in the board meeting, there were other long pauses of 33 seconds and 29 seconds. In retrospect I am not surprised that students did not contribute as readily to the conversation, especially considering that their contributions could have been met with a stern redirection from me. Interestingly, the comment that Colin made in the beginning of the segment was also a difference, and not a similarity, yet I said nothing to him. To what extent would students be willing to voice a comment knowing that I could respond without waiting just as I had done with Garrett?

Later in the conversation, in the midst of those periods of silence, this exchange occurred:

SH: *Can you talk more about the slope? And there's some other thing that we haven't addressed from the equation as well.*

[33 seconds]

SH: *Colin has spoken three times, Garrett spoken once, Moe has spoken once, let's go. This is your conversation. If you've got a question, be sure to voice it.*

[29 seconds]

Lyle: *We don't have anything to say, so why don't we go onto the differences?*

SH: *Because you haven't, you've said the slopes are similar, what do you mean by that? And there's another part of the equation as well that we haven't addressed at all, besides the slope for the first configuration. So that's why I'm, I'm comfortable with that awkward silence. Because somebody will recognize that at some point, and maybe that will be you. What do you think? What makes the slopes similar?*

(BdMtg 1, 0:08:31)

I thought I had provided enough scaffolding with the comment I made in the beginning of this episode when I asked the students to talk more about the slope and explain more in the equation, but 33 seconds of silence followed that prompt. For some reason, to break the tension being held in the silence, I provided the class with a contribution count; I said how Colin had spoken three times, etc. In my head I noticed that the contributors thus far were all males, but I did not know how to address this fact. I had not even told students that I was tallying who responded. Instead, I continued by saying ‘Let’s go,’ an imperative statement giving an order to move forward. I then said ‘This is your conversation,’ in an attempt to place ownership on them, yet as the person who was doing the tallying, I was placing value on their remarks and I likely limited their opportunity of ownership in the discussion. I followed up with another imperative mode, ‘be sure to voice it,’ but instead of students talking there was another period of silence. Another boy breaks the silence by saying ‘we don’t have anything to say.’ He used the pronoun ‘we’ to speak as a representative of the group and made this statement in declarative mode, and he then asked a question using ‘we’ again – ‘why don’t we go on to the differences?’

I responded without pause, ‘Because you haven’t,’ and this immediate response employed an accusatory tone, placing blame on the students and coming from my defensive response to Lyle’s comment. I continued by saying, ‘You’ve said the slopes are similar,’ which was a declarative statement rephrasing what had been contributed. I continued by asking, ‘What do you mean by that?’ but it was not clear if this interrogative remark was directed to Lyle or to the class; this ambiguity of the pronoun ‘you’ could have come across as speaking to the class or to Lyle in particular. Just as he used ‘We’ to singularly speak for the group, I used ‘You’ to collectively single him out.

This episode was unlike any I experienced in any of the group discussions because of both the silence and the dynamics of the participants involved, but it is indicative of a tension I face in facilitating discourse in my classroom. For the last five years, I have been wrestling with the degree of scaffolding necessary to make board meetings as successful as possible for student learning. As I already noted, in the beginning of this group discussion, I provided some scaffolding for the content of the conversation by describing the general process of discussing similarities between and differences among the whiteboards. However, if the intention of the board meeting was to emulate the process of science by having students looking for patterns in the data and in engaging in conversation that result in a scientific model, it would be more beneficial to focus the conversation explicitly on what students should be examining. While I had hoped that students would automatically examine and discuss the graph shapes, best-fit correlations, meanings and interpretations of intercept and slope would occur, the discussion of these attributes did not happen readily. Extended periods of silence and uncomfortable student and teacher interactions combined to yield a challenging experience for facilitation. My journal reflected this unease: “No one mentioned the shape of the plots. After what felt like an eternity, Lyle mentioned the fact that there is nothing else to say, which is why everyone was quiet” (Journal, Unit 2 BdMtg, Sept 17, 2013). Explicit scaffolding directing students to those attributes – shape, correlation, intercept, and slope - would result in less time opening up the problem and more time exploring student views and introducing the scientific story, and such scaffolding would be better because students would know what to say. More time could be spent making meaning from those contributions.

According to Vygotsky (1978), student learning occurs during the phase of internalization, as students make sense of ideas that have been introduced on the interpsychological (social) plane and move into the intrapsychological (individual) plane. As the instructor, once the scientific view has been introduced, it is my responsibility to guide students and support their internalization of the scientific view that has been presented. On the teaching purposes keyword map (Figure 4.1), this guiding to support internalization is the fourth horizontal band from the top. In order for each discussion, to contribute to meaning making, a portion of discussion needs to guide students to support internalization.

Content of interactions: Social language. Because the intention of these conversations was for students to engage in the analysis of data, to engage in argumentation about the meaning and interpretation of the variables being explored, and to construct a model that can serve as the basis for the upcoming unit, it would be expected that the scientific social language used by both the teacher and student would dominate these discussions. Students did engage in the scientific social language, such as when Colin said, “Our slopes for the first um, graph seems to be the same or close to it” (BdMtg 1, 0:06:54) or when Tom stated that on graph “the x-axis, or the axises, are switched” (BdMtg, 0:25:28). Garrett stated that “Some have a negative slope” (BdMtg 1, 0:16:07), and when describing her group’s second experimental configuration one stated “We started behind the origin” (BdMtg 1, 0:25:53). In these examples, the words “slopes”, “axis”, and “origin” are words that students may have used before, especially in a math class, but because we have introduced them in physics and constructed a meaning for them in this context, the students are demonstrating the scientific social language. They tend to not use such words in everyday conversation outside the classroom. I also used the scientific social language; for example, when seeking elaboration, “You've talked about the correlations - they seem to be similar. Can you talk more about the slope?” (BdMtg 1, 0:08:31), and when clarifying the interpretation of the intercept, “Okay, so you've addressed the intercept, now then should it be zero for the first configuration?” (BdMtg 1, 0:12:31). These sample contributions are using vocabulary such as correlation, slope, and intercept, and although slope and intercept are typically incorporated in high school algebra classes, correlation is usually reserved for statistics courses. However, these terms are specific to the process of analyzing graphs that was introduced in this course at the beginning of the year and therefore have a situated meaning that was developed in the context of this physics course.

Although I had hoped that the teacher and student use of the scientific social language would dominate the discussion, the keyword map shown in Figure 4.2 shows this is only partially true. The third horizontal band represents the presence of the scientific social language that I used, and that dominated the conversation.

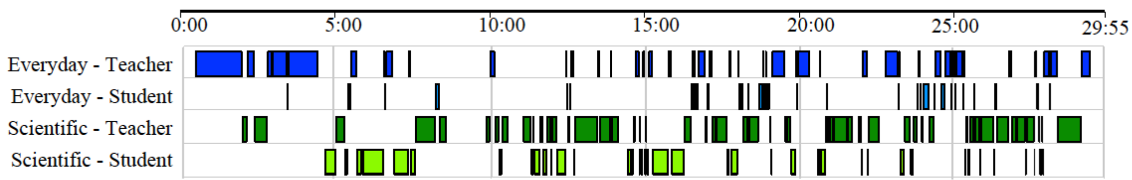


Figure 4.2. Board meeting 1, social language usage keyword map.

Even though the speech genre intended students to engage in the conversation and contribute with minimal prompting (no hand-raising, or calling upon by the teacher), the outcome was not consistent with this expectation. The high density of bands coded for Scientific-teacher indicates my pervasive presence in the discussion and my repeated use of the scientific social language. Using Gee's (2011) deixis tool, the use of these terms does assume that the students are familiar with their application and meaning because we conducted these analyses in the first unit of the course; however prior to this conversation I did not have specific data that would indicate that level of understanding that students actually had with these concepts.

In looking at the keyword map, I was struck by the sheer amount of talking that I did; while I anticipated that the introduction would be necessary to establish the norms and expectations for this speech genre, the frequency of coded teacher contributions indicate that my voice dominated the conversation. In addition, not only was it my voice that was most present in the conversation, the social language that I used most often was the scientific social language. While this extent of scientific social language usage could be viewed as a model of how to engage in the Discourse of being a physics student, it could also have detrimental effects for student understanding as well; students not familiar with these terms might feel marginalized from the conversation. Lemke (1990) explored the relationship between student engagement and the language that was used in the science course. He found that in in about 90% of instances that used colloquial rather than the scientific language “the engagement of the class with what was being said increased significantly” (p. 136). In addition, students “are three to four times as likely to be highly attentive to ‘humanized’ science talk as they would be to ‘normal’ science talk in the classroom” (p. 136). Similarly, Arnold Arons (1997) advocated the recognition that “a scientific concept involves an idea first and a name afterwards, and that understanding does not reside in the technical terms themselves” (p. 345); by introducing the concepts first, students can make better sense of the semantic relationships associated with the scientific term.

Although there were no English learners in this data sample, if other science teachers demonstrate similar language behaviors then the consequences would be even more detrimental to students who have not been explicitly introduced to the semantic connections that are inherent in the scientific social language (Lemke, 1990).

To analyze this distribution of talk further, the time code data was extracted for this conversation, and the total contributions were determined and are shown in Figure 4.3.

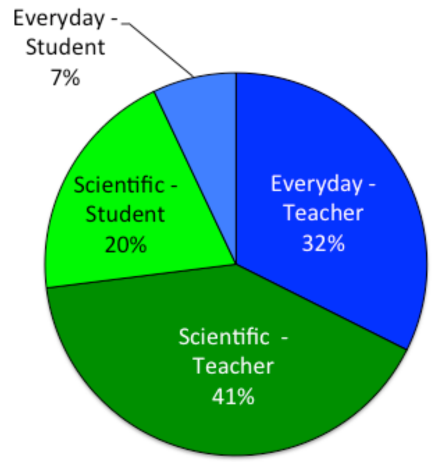


Figure 4.3. Board meeting 1, distribution of social language.

Including both my everyday and scientific social language contributions, I spoke for about 73% of the conversation. If this is supposed to be a student discussion, then these numbers make it apparent that I need to make more space for the students to speak. The scientific social language was used for a total of 48% of the discussion, with 7% demonstrated by students and 41% by me. This discrepancy might indicate that student discussion needs to be scaffolded so students know how to enter the conversation. Otherwise, as already mentioned, I need to consider the possibility that students were being excluded from the conversation not because they did not know how to enter the conversation but because they did not speak the language of science.

Content of interactions. Prior to conducting this analysis, I had not specifically considered the nature of the scientific contributions (description, explanation, or generalization) before or during the board meeting. Based on the nature of the content, I expected the conversation would focus on empirical descriptions as students examined similarities and differences between the graphs displayed on the whiteboards. In addition, students would include empirical explanations as they discussed the meaning of the vertical intercepts of the position versus time graphs and the meaning of the slope of the position versus time graph. Overall, my goal was for students to work toward a model for constant velocity motion, which could be classified as a generalized empirical contribution.

The keyword map for the content of interactions is shown in Figure 4.4.

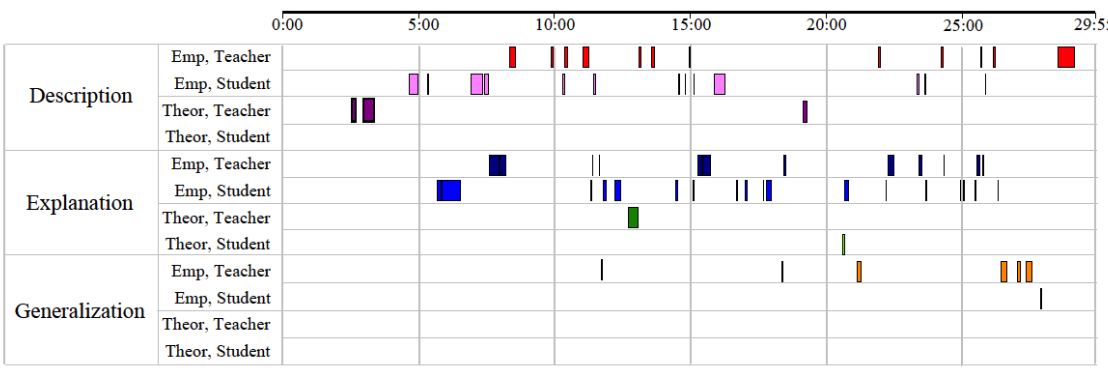


Figure 4.4. Board meeting 1, content of interactions keyword map.

The map indicates that the students and the teacher both shared in discussing scientific content associated with the phenomena. For example, when discussing the graphs, one student provided a description of "Not all of them start at the origin" (BdMtg 1, 0:16:13). Likewise, when interpreting the slope, a student explains the slope by saying "as we measure it meters so it's going that many meters per second" (BdMtg 1, 0:14:27). Statements such as these are representative of many of the student contributions to the discussion.

One contribution could be considered several different types of scientific content. For instance, when evaluating the vertical intercepts on the graphs, one student claimed that "Everyone has a really small Y intercept because we started at zero, so it shouldn't be there" (BdMtg 1, 0:11:27). In this single sentence, the student contributes a description, explanation and a generalization. The empirical description of "everyone has a really small intercept" is describing what she observed from examining the equations on the whiteboards around the circle. In addition, by saying that "we started at zero," she provides an empirical explanation for this lack of an intercept by claiming that the intercept would not be present because the toy buggies all began at the origin of the experimental configuration. Finally, she finishes with a generalization by stating that "it shouldn't be there," asserting that any time an object starts at the origin there should not an intercept.

My contributions affected the content of the interactions; as the facilitator of the group discussion, my comments and questions directed students toward descriptions, explanations, or generalizations. By asking, "What makes the slopes similar?" (BdMtg 1, 0:10:10) I was prompting students to describe the similarities they observed. At another point, I discussed the vertical intercepts by saying:

> "Almost everybody has an intercept written down for their initial configuration. We need to talk about that `cause you're gonna have to do that when you justify this in your write up. You know so tell me what that intercept means or should it be there. You know, you need to talk about the intercept, go ahead" (BdMtg 1, 0:11:05).

However, the most clear direction that I provided in this statement was in the middle of the contribution – 'tell me what the intercept means or should it be there.' This directive clearly asked the students to provide an explanation and even evaluate the intercept, but it was sandwiched between less clear facilitation. The remarks I made in this passage were vague; when I said the students had to justify this in their write up, I didn't discuss anything else about the write up at this point. Similarly, a comment that students most likely hung onto was the vague 'talk about the intercept, go ahead.' Similarly, I provided equally vague instructions later when I asked "Can you talk more about the slope?" (BdMtg 1, 0:08:31). This prompt might have been asking students to provide a description or an explanation, but if I had provided more clarity in what I was seeking, there might have been more specific description or explanation by students.

There was limited demonstration of generalization in this conversation, but the contributions coded as generalizations are located mostly toward the end of the discussion. For instance, when summarizing the role of the vertical intercept, I said "The vertical intercept - that represents your position at the time equals zero" (BdMtg 1, 0:27:22). The presence of generalizations is consistent with modeling theory; the purpose of the board meeting is to develop a relationship between variables that can serve as a model with predictive power. Emphasizing the role of generalizations then might reinforce different attributes that comprise the model and lead to greater student understanding.

This aspect of the framework, content of interactions, is what separates analyzing science talk from analyzing the discourse of other subjects; considering the intended outcome for the discussion assists the instructor in helping students develop the scientific story and making it accessible to all students. If I had realized that I was seeking an empirical generalization, I could have facilitated the conversation more in that direction, emphasizing that we wanted to identify a relationship between the variables that provide predictive power, and thus enabling us to apply this model to a variety of circumstances. In this first board meeting, that did not happen smoothly, and this is an example of how my dominating the conversation could have implications for the direction and outcome of the conversation. My goal was to arrive at an empirical generalization of constant velocity motion, yet I made only a few generalized statements and students only made one generalizing contribution. Being aware of the content types can affect the statements that students contribute to the discussion; I could pose questions that specifically elicit descriptions, explanations, or generalizations. Nevertheless, being more intentional and knowledgeable about the nature of the content outcome can shape the path I might choose to reach that outcome.

Communicative approach. When I began this research, I hoped to explore the extent to which my classroom was dialogic; I wanted my classroom to be a place where students' ideas were welcomed and heard. I valued the presence of the interactive/dialogic communicative approach, and my belief at that time equated the presence of student ideas with the opportunity for student learning of scientific concepts. However, upon further research and understanding the role of communicative approach within the Mortimer and Scott (2003) framework, it became apparent that dialogic discourse is only one facet to meaning making in the science classroom; to introduce and develop the scientific story, an authoritative approach is necessary, otherwise students might never arrive at the scientific view that is the goal of the discussion.

The keyword map for the first whiteboard discussion's communicative approach is shown in Figure 4.5.

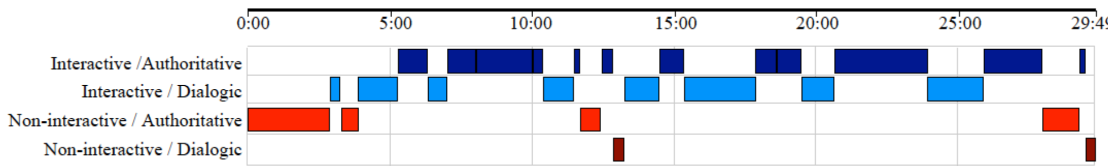


Figure 4.5. Board meeting 1, communicative approach keyword map.

In the discussion, there was a large component of interactivity, with an alternating sequence of authoritative and dialogic components. This map shows that there was a considerable presence of an interactive-dialogic communicative approach; students' ideas were being voiced in the class. Sometimes this interactivity came from follow-up remarks, such as "Tell me more about that, Jason," (BdMtg 1, 0:11:52). Students responded to my questions about the vertical intercept by saying, "because of our human error, then with the line of the best fit it isn't going exactly go through this point" (BdMtg 1, 0:12:11). Sometimes this opportunity arose from questions I posed, such as when comparing the two configurations presented on one group's whiteboard I asked, "How would you describe differences with theirs?" (BdMtg 1, 0:23:25). If I had asked 'What are the differences?,' there is less room for interpretation, but asking '*How would you describe* the differences?' made the question divergent and provided a space for student ideas to enter into the discussion. Karri responded to this prompt by saying, "It's like the slope's about the same, so it looks like she might have just started somewhere else" (BdMtg 1, 0:23:37), providing a description and explanation in her contribution.

In addition, there was also a considerable presence of the interactive/authoritative approach, which was consistent with the introduction of the scientific story. For instance, in discussing the meaning of the intercept as the object's starting position, I posed the question "Are there any groups from what you see, that started somewhere other than zero?" (BdMtg 1, 0:18:23). Colin responded by pointing at a whiteboard across the circle, saying, "That one, um, and I think ours, yeah" (BdMtg 1, 0:18:42). He continued by saying, "they look like they started at four instead of zero" (BdMtg 1, 0:18:52). Jason chimed in with, "We started at one for the second part" (BdMtg 1, 0:18:59). There are definitive answers to this question, and its convergent nature leads to specific responses that assist in the development of the scientific story; namely, if the mathematical model in question indicates the presence of a vertical intercept, then the object being represented was at some position other than the origin when the clock started.

There were several portions of a non-interactive/authoritative approach when I was introducing the task or introducing something specific at the midpoint and end of the conversation. After we had discussed a guideline for helping determine the significance of the vertical intercept (known as the 5% rule), I needed to communicate to the students how to represent on their whiteboards whether they invoked the 5% rule in their own analysis. I stated:

> "the way you can note that on a whiteboard in the future is writing the intercept as Logger Pro gives it to you, and then put a line through it like an arrow saying it goes to zero because of the 5% rule. Our reasoning tells us it shouldn't be there.

> So then 5% rule says it's just coming from measurement error" (BdMtg 1, 0:12:44).

This statement provides explicit instruction for the method I wanted students to use to communicate one aspect of their analysis. It is an example of me sharing my expectation for notation without room for variation or interpretation, and it is a clear example of a non-interactive/authoritative communicative approach.

Finally, the non-interactive/dialogic approach appears two times during the discussion, once in the middle and once at the very end of the discussion. When we reached the middle of the discussion, I summarized our findings to that point by saying:

> "Now we have identified that that they all should have an intercept at zero `cause they start at the origin. Any intercept we're getting is coming from measurement error we can disregard it from the 5% rule. We've said that all the slopes are positive and that the number represents the speed. Are we comfortable with that?" (BdMtg 1, 0:15:27).

As I learned more about the non-interactive/dialogic communicative approach, I found similarities to the discourse move of *revoicing* (O'Connor & Michaels, 1993); in revoicing, the teacher restates the contribution that a specific student has made, often referring to that student by name. Not only does this action mark the comment as important, but this revoicing of that student's idea can promote the status of those students in the eyes of their peers. A deliberate use of the non-interactive/dialogic approach, especially revoicing, at midpoints and endpoints in the discussion may be an important tool for assisting in the status development of students in class, particularly for those who are considered low-status by their peers.

Overall, in examining the communicative approach keyword map, I was pleased to see the extent of the interactive/dialogic approach present in this discussion; there are opportunities for student's ideas and views to be heard, but I need to reconcile this with the amount of actual talking the students are contributing. The keyword map shows that the use of an interactive/authoritative approach often served as a counterpoint to the interactive/dialogic approach during the introduction and development of the scientific story. Moreover, my role as information provider (in the non-interactive/authoritative approach) occurred at the beginning to establish norms and expectations, but it also appeared briefly in the middle and again at the end of the discussion. Finally, the communicative approach of non-interactive/dialogic is only present in small amounts midway through and at the end of the discussion.

Patterns of discourse. As an instructor wanting to increase the presence of student voices in the classroom and also interested in moving those voices beyond single word or phrase contributions, I was very curious to track the interaction patterns during these discussions. I have often been told by my supervisors that I had effective questioning techniques, so I had hoped that the patterns would support this claim by revealing a considerable number of interaction chains (*I-R-F-R-F*), rather than single word or phrase responses represented by the triadic dialogue (*I-R-E*).

The keyword map for this board meeting's patterns of discourse is shown in Figure 4.6.

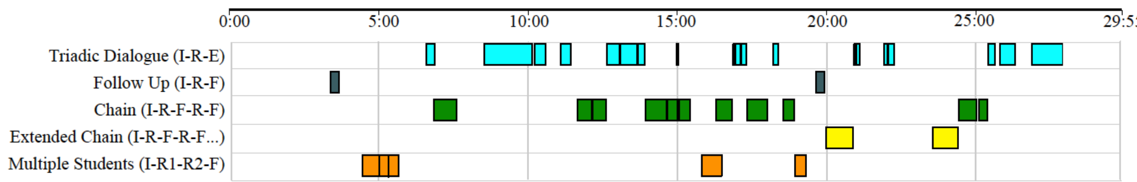


Figure 4.6. Board meeting 1, patterns of interaction keyword map.

There is a considerable presence of interaction chains as represented by the middle band across the keyword map. Many of these interaction chains have nuances that are worth discussing. For instance, hoping to help students realize the number portion of the slope represents the speed, I asked students to interpret the slope in the context of the toy buggy's motion:

SH: *So then my question is what does that number mean? Let's give it an interpretation of that slope.*

[18 seconds of silence]

Lorna: *It means that it's going, like for as we measure it meters so it's going that many meters per second.*

SH: *Can you use your number then?*

Lorna: *0.477 meters per second.*

SH: *0.477 meters each second*

(BdMtg 1, 0:14:02)

It is interesting that 18 seconds of silence elapsed in waiting for a response to this question, but the student does submit a correct interpretation of the slope in this context. She first considers the units that were used in this activity (meters) with the number of meters traveled in each unit of time (seconds). I follow up by asking her to apply her group's specific number for the speed (0.477 meters/second), but then I restate her answer, replacing the word ‘per’ with the word ‘each.’ This replacement was done intentionally because of my experiences observing students struggling with the meaning of the word ‘per’. Although some years I have had explicit discussions about why we will not use the word ‘per’ in our class, I did not have such a discussion this year, and I wonder the extent to which this word replacement was acknowledged and understood by the students. Lemke (1990) would recommend that I be explicit about such language usage in the future, to ensure that everyone understood the role of ‘per’ in the classroom.

In this next example, the students have been asked why the data analysis software Logger Pro is indicating an intercept (a starting position other than at the origin) when in fact all buggies in this configuration did start at the origin:

SH: *Why is Logger Pro giving us the intercepts?*

Jason: *‘Cause it's going with the slope, at what it would approximately be at if you, X were zero.*

SH: *It's going with the slope. Tell me more about that Jason, you say it's going with the slope, the slope of what?*

Jason: *Um, predicted line.*

SH: *The best fit predicted line*

(BdMtg 1, 0:11:38)

In my follow up move, I asked the student to elaborate on his response (‘tell me more about that’), but then I did not stop there and give him the chance to do so. Instead I continued talking and asked a convergent question that clarified what is resulting in the given intercept. The student responded by stating the slope is from the predicted line, and I modified his response by referring to it as ‘the *best fit* predicted line.’ This clarifying insertion was intended to make clear to the entire group that although the buggy itself might have been at the origin at time *t=0* seconds, the application of a best fit line rarely would pass through the origin because of measurement error during the data collection. It would have been interesting for me to stop at the original follow up move ('Tell me more about that'), and provide a space for the student to respond. Although it might have taken a little more time, the process of him working through the explanation would have been beneficial for him to experience and for his classmates to observe Although there are several examples in which multiple students were engaged in the interaction pattern, most of the interactions involve the teacher as the controller of the interaction. The interaction pattern that demonstrated the most teacher control was the triadic dialogue, and there were substantive segments where this was the dominant interaction pattern. It was used to identify specific concepts or understanding that is consistent with the scientific view. For example, when trying to support the claim that a given intercept is a result of measurement error rather than it representing something meaningful in the object's motion, this exchange attempted to help students invoke the 5% rule:

SH: *Reasoning is saying that, how can we justify getting rid of it, after we use our reasoning and recognize that it shouldn't be there?*

Colin: *Is that the 5% rule?*

SH: *The 5% rule.*

(BdMtg 1, 0:12:37)

I repeat the student's response as a means of emphasizing its importance. However, I did not identify the student by name in my follow-up move, so I did not take full advantage of the revoicing strategy proposed by O'Conner and Michaels (1993). Similarly, in this next exchange we were trying to clarify the meaning of the slope's sign when the object's motion was represented on a position versus time graph:

SH: *So then what does the sign of the slope represent?*

Girl: *It's going, whether it's going forward or backwards.*

SH: *Which way the car is travelling, forwards or backwards.*

(BdMtg 1, 0:16:58)

In this exchange, I repeated the student's response, again making a substitution for a student's word (travelling inserted instead of going). I do not have a pedagogical reason for doing this, and I wonder if changing the student's terminology has a detrimental effect in the classroom; specifically, I wonder if there could be a negative impact on status from this discourse move.

Interestingly, my understanding of triadic dialogue has evolved as a result of this research. At the beginning of this project, I had strong reservations about triadic dialogue, and I think that my perceived limitations of this discourse pattern were based on classroom observations in which the triadic dialogue was the main form of interaction and students had minimal opportunity to voice their ideas. However, Mortimer and Scott (2003) maintain that this pattern is not inherently bad, but rather that it often seems to signal the interactive/authoritative communicative approach and the development of the scientific story; consequently, this discourse pattern has an important role in the science classroom. Unfortunately in this board meeting, the use of triadic dialogue was not consistent with Mortimer and Scott's (2003) view; in the first 12 minutes of this discussion no scientific views were being introduced, yet the triadic dialogue was definitely present. It was used more as a means of controlling the pacing and direction of the discourse. Overall, the triadic dialogue interaction pattern is one of the most pervasive forms of classroom discourse (Lemke, 1990), and it certainly has its presence in this discussion as well.

Teacher interventions. When considering the facilitation of this discourse, I expected that there would be a general flow to the teacher interventions as time progressed throughout the board meeting. Specifically, I expected that I would begin by shaping ideas, selecting ideas, marking or emphasizing those ideas, and then sharing those ideas to make them accessible to all students in the class. In addition, I surmised that I would review the main points at the end of the discussion. Admittedly, I had not considered the extent to which I would check student understanding through the course of the conversation. Moreover, while the flow of teacher interventions outlined in the analytical framework seem seemed pedagogically normal, it lends itself to models in which the teacher facilitates the discussion.

The keyword map for the board meeting's teacher interventions is shown in Figure 4.7.

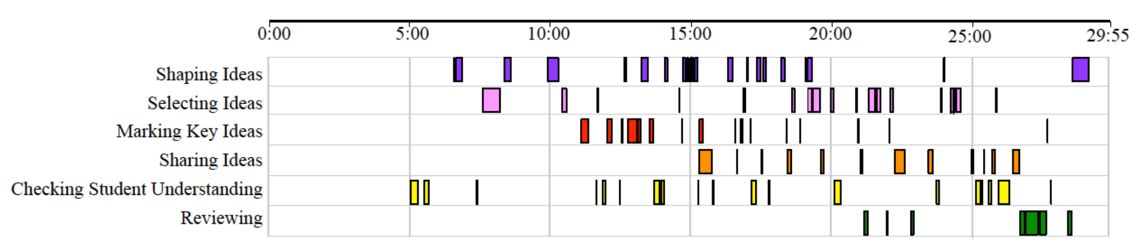


Figure 4.7. Board meeting 1, teacher interventions keyword map.

At first glance, the map shows quite a variety of teacher interventions; this distribution revealed that facilitating discourse is complicated work as each contribution takes on one role or another. There seems to be a general progression to the interventions; on the keyword map the general trend of intervention placement seems to be slanting downward to the right. In other words, as time progressed more interventions were used sharing ideas and reviewing rather than selecting or marking ideas.

These interventions constitute how the scientific story was introduced and made available to all the students in the class. For example, after a student shared some differences between the whiteboards, I selected two of those differences by following up with "So what do those things mean if it doesn't start at the origin and it doesn't have the same sign slope?" (BdMtg 1, 0:16:18). This focused the conversation on how the students could further discuss starting position and the direction of motion. When I asked students the meaning of the slope's sign, a student responded and I said "Okay so the movement is in the other direction" (BdMtg 1, 0:16:45) and marked the key idea by repeating what the student had said. After students had arrived at an important point in the discussion about evaluating the intercept, I shared our reasoning with the class be saying "Any intercept we're getting is coming from measurement error - we can disregard it from the 5% rule" (BdMtg 1, 0:15:27). I checked student understanding by asking "How do people feel about that? You guys had the slope that's negative. Do you agree with that? You're nodding 'yes'?" (BdMtg 1, 0:17:08). At the end of the discussion, I began reviewing what had been discussed by saying "Let's try to summarize what I think I've heard you say" (BdMtg 1, 0:26:53).

The varied distribution of interventions reveals that with each verbal comment that we make as teachers, our words are acting in ways that might not always be obvious to us. I think this map shows the dynamics of discourse facilitation, and while some teachers might just do this “naturally,” being deliberate about knowing that we shape ideas, select ideas, etc., can allow us to be more mindful about our facilitation of such discourse. I also like the fact that the framework includes the intervention category of sharing ideas; this idea resonates with my desire for access and equity in the classroom. Specifically, I think that developing the scientific story and making it available to all students by sharing the ideas places an appropriate level of priority on making sure that all students have a chance to understand the material.

I did struggle with one category of the teacher interventions aspect of the framework. Specifically, I was initially pleased with the number of codes for Checking Student Understanding, because I thought that as a teacher I should always be using formative assessment to gauge the level of understanding in the classroom. However, after reading the transcripts and listening to the audio files, I realized that the instances I had coded for Checking Student Understanding were often me simply asking “Do you understand this?” or “Does that make sense?” without really providing the space for students to respond. While the questions were not rhetorical, they certainly come across as such when examined closely. This is a limitation of the coding system as I used it; with the framework the transcript might indicate one type of teacher intervention but in reality it was not in the spirit of the intervention. To better measure the level of ‘checking student understanding of the scientific story,’ it would be beneficial to measure explicit uses of formative assessment moves.

Overall, the analysis of this group discussion provided an opportunity for me to examine my practice of discourse facilitation through the various aspects of the analytical framework. In addition, it helped me consider the tensions I experienced in the facilitation of this board meeting. Specifically, I encountered tension in accommodating the silence that occurred within the conversation, and I did not consider the possible reasons that the students demonstrated silence. In addition, I experienced tension in providing the appropriate level of scaffolding necessary to promote discourse; providing too much direction could result in a loss of the discussion dynamic, but providing too little support could result in students not knowing what exactly to contribute. Next I discuss the facilitation of a second group discussion.

Board meeting 2: Newton's second law

As a reminder, the second board meeting was chosen because the scientific content involved required some manipulation of the entire class's data to develop the model, and I wanted to examine how I facilitated this discussion dynamic. In analyzing this meeting, I was interested in the effect of a mini-lesson's presence in the white board discussion. This conversation was based on a laboratory experiment in which students used a modified Atwood's machine to examine the acceleration of a cart experiencing various unbalanced forces. Student groups each were assigned a cart system with a unique mass, and they used motion detectors to measure the acceleration and force sensors to measure the unbalanced forces applied to each cart system. The force was applied uniformly by using hanging masses connected by a string travelling over a pulley and tied to the cart. The track was angled slightly downhill to allow gravity to eliminate any effect of friction.

The goal of the laboratory experiment and subsequent board meeting was to establish Newton's Second Law of motion, namely that the acceleration of an object is directly proportional to the unbalanced force it experiences and inversely proportional to the object's mass. Because the object's acceleration was related to two variables (unbalanced force and mass), I knew that there was going to be a segment in the discussion in which I would help students recognize the inverse relationship between mass and acceleration. In preparation for this segment, I copied some data from each group the day before the board meeting so I could conduct a sort of "meta" analysis using data from all my physics groups in all classes.

To prepare for the board meeting, students analyzed the data of acceleration versus unbalanced force using Logger Pro software, and then they drew their group graph and corresponding equation for the line of best fit on their group whiteboards. They also wrote their system mass on the whiteboard. As before, the classroom was organized so that all students could sit in a large circle and see their classmates' whiteboards (Desbien, 2002).

The dynamics of this board meeting were a little different than other board meetings because of the need to guide the development of the acceleration-mass inverse relationship using all student groups' data. This was expected to occur after students noticed that as the mass of the system increased, the slope of the displayed graph decreased; I expected that there would be a mini-lesson in the midst of the board meeting.

This group discussion/lesson structure was introduced to me during my Modeling Physics workshop in 2008, and as a participant I was intrigued by the use of multiple data sets to arrive at a relationship. I remember following the instructor closely as he led us, and I thought it was effective that even using student data we could arrive at a relationship that was statistically strong. Because I already understood Newton's Second Law rather well, conducting this lab as a workshop participant served as a verification exercise for me; this is not true for students, and I had hoped that by using this 'meta-analysis' in my own classroom this would be more meaningful for students to arrive at the mass-acceleration relationship than other strategies I had done in the past. In this section the use of the analytical framework is helpful for assessing the dynamics of the mini-lesson as it was incorporated into the board meeting.

Teaching purposes. Because the students had already experienced board meetings, I hoped that we would spend less time opening up the problem and more time exploring student ideas about the relationship between acceleration and unbalanced force. In addition, I hoped to successfully facilitate the introduction of Newton's Second Law, so I expected that there would be a portion in which I would be introducing the scientific story, after which I would help students make sense of that relationship. The keyword map for the second board meeting's teaching purposes is shown in Figure 4.8.

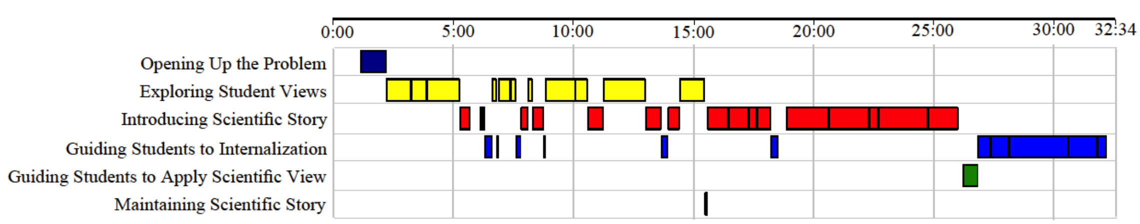


Figure 4.8. Board meeting 2, teaching purposes keyword map.

The keyword map shows that there was only a brief time opening up the problem, and I included statements like:

> "We make claims to try to look for patterns, to look for relationships. We do that by talking about similarities on the whiteboards, and the differences on the whiteboards. And then from there we hope to try to support all of our claims using the evidence that we have in front of us. Um, remember our style is such that we kind of speak out just to answer questions" (BdMtg 2, 0:01:33).

This reminder was intended to provide some structure for the content of the discussion by saying that we first talk about similarities and then we talk about differences, but I was not specific is stating that we are looking for those similarities or differences in the graph shape, the correlation of linear fit, the vertical intercept or the graph's slope. The procedural norms of how to be a participant in the board meeting were briefly noted by saying that we speak out; as in the first board meeting that was analyzed, there was no elaboration on the reasoning for why this is the norm of the speech genre.

Looking at the teaching purposes keyword map, in the first half of the discussion we were mainly exploring student ideas. For example, as we considered the similarities between groups' correlations, one exchange went as follows:

Colin: *We should all have the same linear fit.*

SH: *All the same linear fit, what do you mean?*

Colin: *Like if the correlations are the same, so should the linear fit.*

Karri: *The graph would be more like y=x graph*

SH: *Well, y=x….*

Karri: *Like a straight shot through the middle, instead of being closer to the bottom, or closer to the top.*

SH: *Okay, that's a good question. We'll have to evaluate if it looks like y=x or in our case, acceleration equals unbalanced force. So keep that in mind as we continue this conversation.*

(BdMtg 2, 0:06:54)

In this segment, we were just beginning to establish similarities between groups, and the students contributed these ideas in an attempt to elaborate on those similarities. Colin claimed that the linear fit would be the same if the correlations were the same, and although I was unsure what he was proposing, Karri shared her thinking about the matter by describing the shape would resemble the shape of a plot of $y = x$. I do not know if she was attempting to clarify Colin's statement for me or if she was introducing a new idea, but when I started to address this incorrect idea, she followed up by describing the shape of the $y=x$ plot. Instead of stating that she was wrong, I acknowledged her prediction by naming it as a good question. I delayed the evaluation of this incorrect remark by saying that we would "keep that in mind" as we continued the conversation. In retrospect we never did return to this question; I forgot about it entirely, and the student never followed up with it either.

The keyword map shows that there were some portions introducing the scientific story in the first half of the discussion. One example was actually introduced by a student when he said, "A lot of groups um, have intercepts that they are able to discount, just because they are within the 5% rule. And that's important because it shows ah that ah that they're most likely at zero, when there was zero force there was zero acceleration" (BdMtg 2, 0:07:50). This student is using reasoning to interpret the meaning of what is being represented at the origin of this graph. In the first board meeting I discussed, the students explored position versus time graphs, and any vertical intercept on that graph represented the object's position at the first clock reading. However, in this case the student used his reasoning to establish that when there is no force the object should not undergo acceleration. His statement is making a connection as well to the previous unit in which students explored Newton's First Law of motion, where students learned that balanced forces will not change an object's motion. By his claiming the reason for its importance, he is acting as an information provider to the other students.

The scientific view was introduced during the second half of the discussion, and the keyword map (Figure 4.8) shows the prevalence of this theme. This introduction of the scientific story was grounded in the mini-lesson in which I was walking students through the process of establishing the strength of an inverse relationship, and then conducting a unit analysis to better understand the units obtained when determining the slope of a new plot. For example, I said, "And I want you guys to just follow along as we try to explore what this graph is telling us. Because it's telling us that the slope of your graph is related to 1 over the mass. Does that make sense?" (BdMtg 2, 0:19:06). Interestingly, the statement begins with the phrase "as we try to explore," yet in the very next sentence I give a declarative statement that told the students about the slope of their graphs. There was no exploration and there was no "we," but rather it was simply a case of me telling them what the graph meant.

In the actual introduction of Newton's second law, there was a little space for students to share their ideas in the introduction and development of the scientific story:

SH: *Let's take your graph on your whiteboard, and let's just write a general equation, letters only, no numbers. So what are we finding, in the form of $y = mx + b$? Use your graph as the example, what is our y-axis?*

Shawn: *Acceleration.*

SH: *Acceleration. What is the horizontal axis?*

Colin: *Unbalanced force.*

SH: *Unbalanced force. I'm gonna represent that by the sum of the forces, we've used that before. And our slope, we just determined through unit analysis is actually equal to what?*

Colin: *One.*

SH: *One?*

Joy: *Over the mass.*

SH: *Over the mass. Do you see that? The acceleration is equal to one over the mass times unbalanced force*

(BdMtg 2, 0:23:46)

Students responded to the convergent questions as I guided them to the writing of Newton's Second Law. Each statement incorporated a specific instance of the triadic dialogue that was used to build the representation of the relationship suggested by the data. Overall, I demonstrated a high level of guidance to reach this goal, so I was not able to assess the level of student understanding as we progressed through the model development.

Once the relationship was established, then it became necessary to help support students internalize it. For example, when trying to understanding the format of the written equation, one student asked "Instead of like where you have one over the mass times the sum of the forces, can't you just put it sum of the forces over the mass?"

(BdMtg 2, 0:26:50). Another student made a statement that led to another question when he said “As the unbalanced force increases, is close to the correlation of one, um, with the acceleration increases, there's also a direct relationship” (BdMtg 2, 0:27:50). To check the student understanding of various relationship types, I responded by challenging that assertion by asking “Is it direct relationship? So for instance if you double the unbalanced force will the acceleration double?” (BdMtg 2, 0:28:00). After giving students the chance to talk to their neighbors about this question, this exchange shows how there still were struggles with understanding the relationship:

SH: *As we increase the mass what do we say happened?*

Alice: *Uh the acceleration increases?*

SH: *A little louder.*

Alice: *The acceleration increases, I mean um the unbalanced force increases (looking through notes)*

SH: *So you're not gonna see the answer for this one on your graph. What did this graph show us in terms of the relationship between the acceleration and mass?*

Alice: *As the smaller the slope, the larger the mass.*

(BdMtg 2, 0:30:43)

In this passage, Alice responds to my initial question with her own interrogative statement; although I was asking her to provide information to me, her redirected question made her the information seeker. I didn’t hear her response, so I asked her to repeat it, and when she did repeat it she changed her answer. As a student who consistently took quality notes, she began looking at the graph in her notebook to find supporting information. Her final response indicated that she still struggled with the causality of relationships involved in Newton's Second Law; specifically, she made a relationship between the slope of the graph and the mass, but she did not answer the question I posed about the relationship between acceleration and mass. She did not understand the scientific view that had been developed, and as a student who typically was engaged in class, I realized that there were likely many others who also struggled with understanding the relationship that *I* developed.

While the general progression of teaching purposes moved from the opening up of the problem to exploring student views and introducing the scientific story, there were some other interesting features to this keyword map. Considering the teaching purposes as a whole, the exploration of student views ceases after the first half of the discussion, consistent with the portion of the lesson in which I was guiding them through the analysis of acceleration versus mass. The segment toward the end of the discussion in which I inquired about doubling the unbalanced force and whether that would double the acceleration was important to explore, but I am not sure if this was the best time to do so. I felt as though I was pulling students through the development of the second law, and I wonder if it provided too much cognitive demand after the sequence they had just observed. The energy in the students was palpably low, and since they had been following my lecture for over 15 minutes it probably was not the most effective time to ask this extension question.

Content of interactions: Social language. In considering my intentions for this board meeting, I had hoped that students would be more comfortable participating in the board meeting since this was later in the semester. Students' higher level of comfort with me and their peers should have made them more willing to contribute to the discussion. Likewise, I hoped that more students would be more comfortable using the scientific language as they moved into the year as they had more practice using scientific language. Overall, then, I hoped for an increased amount student talking and an increase in the students' use of the scientific social language.

The keyword map for the second board meeting's social language is shown in Figure 4.9.

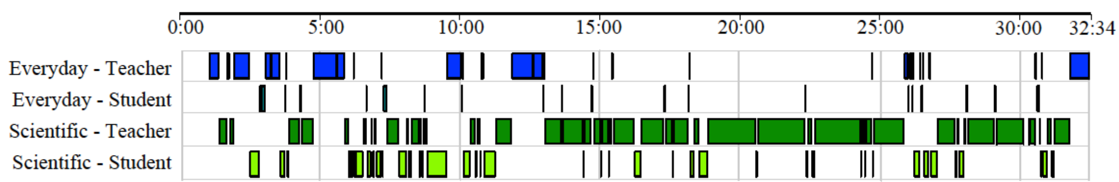


Figure 4.9. Board meeting 2, social language keyword map.

For the first one-third of the board meeting, the students engaged in the scientific social language more frequently than they had in the first whiteboard board meeting. For example, one student who had not spoken in the previous board meeting described the relationship that she observed between the variables on the graph by stating that "as the unbalanced forces goes up the acceleration goes up, it increases" (BdMtg 2, 0:06:17). Similarly, when exploring the relationship between mass and the slope of the plot, another student says,

> "It looks like as everybody's mass goes down the acceleration increases I guess. Like for um, group 6 where their cart is 571 grams, and then their slope for their

acceleration is about 1.7. Then for group 7 where their um, their mass was almost double. It goes down for their slope - it's only 0.913" (BdMtg 2, 0:08:51).

Although the student accidentally uses the word acceleration instead of slope in his first sentence, he correctly uses the term slope in his justification of his claim. He has some hesitancy, which is typical for exploratory talk (Barnes, 1972), but he is willing to make the claim about the relationship between the variables. Interestingly, my response to his use of the scientific social language took the form of the everyday social language: "Okay can other people chime in on that? How do you ah what do you think of Colin's claim?" (BdMtg 2, 0:09:32). In fact, in this first half of the conversation the students engaged in the scientific social language more than the every day social language, while my contributions were more often in the everyday social language than in the scientific social language. However, for minutes 13-26, discussion was dominated by my use of the scientific social language; students had minimal contributions whether they were scientific or everyday social language. In fact, for the second half of the discussion I dominated the conversation.

I extracted the time code data to determine the actual amounts of talking and use of social language, and this chart is shown in Figure 4.10.

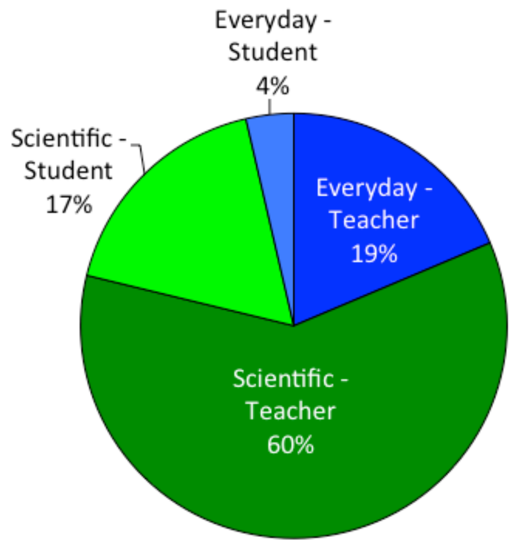


Figure 4.10. Board meeting 2, social language distribution.

Student contributions totaled 21% of the conversation, with 17% of the talking occurring in the scientific social language. I spoke nearly 80% of the time; in addition, the introduction of the new concepts during the second half of the discussion leaned heavily on the use of scientific social language, resulting in my scientific social language contributions amounting to 60% of the talk.

The second half of the lesson was very directed; specifically, after we established that there seemed to be a relationship between the unbalanced force and the object's acceleration, we needed to examine the relationship between the object's acceleration and its mass. I directed students to look at the projection screen and displayed a new graph, on which I plotted the slope from each student group's graph versus their system mass, and as a class we looked for the relationship between the slope values and the groups' masses. Seeing what appeared to be an inverse relationship, we plotted each group's slope versus the inverse of the mass, and we determined that the slope of the students graph was about equal to 1/mass. This was a pretty involved sequence of steps, and I am not sure of the extent to which students really followed it; it required the linearization of data, a data analysis technique students had not used in over a month and may have forgotten. In addition, we were working with an inverse relationship, which they had not used in over two months. Moreover, the discussion also included a unit analysis in which students had to simplify unit expressions, and this is the first instance in which students have been working with units that were not fundamental. As a result, to realize that the slope of each group's original graph was equivalent to 1/mass took considerable guidance. Overall, I am struck by the fact that this board meeting was really finished after 13 minutes; from that point on, it really became a lecture.

Content of interactions. In the second board meeting, I was hoping that students would contribute some empirical descriptions and explanations of the representations displayed on the group whiteboards; this was the third board meeting students experienced in the year, and I had hoped that they were becoming more skilled at being participants in these conversations. I expected that after students identified the descriptions and explanations, I would guide the students to the generalization of Newton's Second Law.

The keyword map for the second board meeting's content of interactions is shown in Figure 4.11.

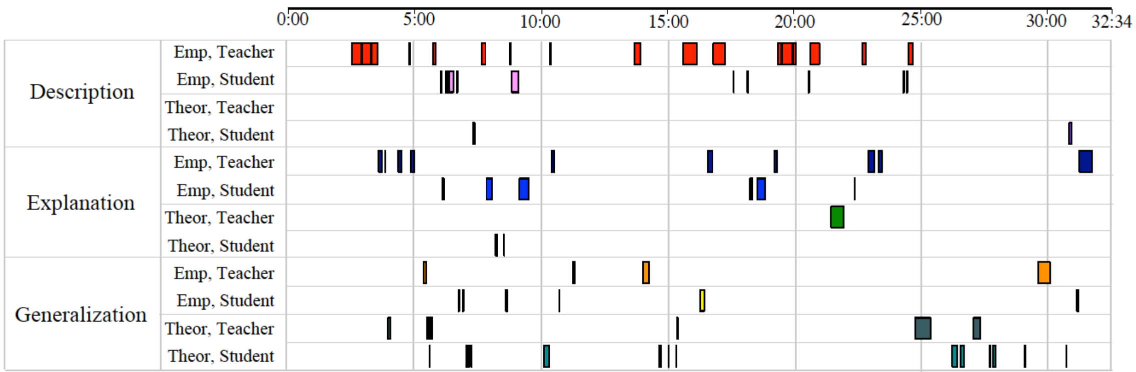


Figure 4.11. Board meeting 2, content of interactions keyword map.

When first looking at the keyword map, I first noticed the presence of my empirical descriptions that were contributed early in the discussion; this was a result of an unusual circumstance pertaining to one group's data. Specifically, immediately before the board meeting they had called me over to show me that their data was puzzling. In our sharing this with the class, one of the group members said that for their data, in two separate instances they measured the "same amount of force, but very different accelerations" (BdMtg 2, 0:03:50), and this led to a conversation about confidence in data and various ways to respond when the data seem inconsistent or illogical.

The keyword map indicates the presence of other scientific content of interactions. Students contributed both descriptions in their statements such as "the graphs are all linear" (BdMtg 2, 0:06:21) describing the general shape of the plot, and explanations for their claims such as "that shows that there was a strong relationship between ah one over mass and the slope" (BdMtg 2, 0:18:33). Unlike the first board meeting this discussion contained more statements of generalization; for example, following the statement that the graphs are all linear, one student posited "wouldn't that be directly related to correlations?" (BdMtg 2, 0:06:42). Another student proposed the relationship that "The smaller the slope um, the more of mass there is" (BdMtg 2, 0:16:16). The presence of generalizations is important because science is always trying to establish meaningful generalizations when it attempts to create models, because it is through the quality of the generalizations that the predictive power of the models is established. In addition, unlike prior board meetings the students made theoretical statements; when one student spoke of an object in general, he claimed that "like the less mass it has, the more it will accelerate - the faster than it accelerates" (BdMtg 2, 0:10:07). Finally, another student related this general behavior to the content studied in the previous unit on Newton's First Law when he stated "In a way this also proves um, the other law as well, because we had zero acceleration the unbalanced forces will equal zero as well" (BdMtg 2, 0:26:14). Theoretical statements are important because in science it is necessary for students to consider phenomena that cannot be directly observed, which can provide a basis for more abstract thinking in physics topics to be studied later. Overall, the identification of the presence of descriptions, explanations, and generalizations is a beneficial step in considering the scientific content of student contributions in class discussions.

Communicative approach. In this board meeting, the intent was again for students to contribute their ideas about similarities and differences in the graphs and equations, thus demonstrating the interactive/dialogic approach. As shown in the keyword map for the second board meeting's communicative approach (Figure 4.12), there is a large portion of the interactive/dialogic approach in the meeting's first half.

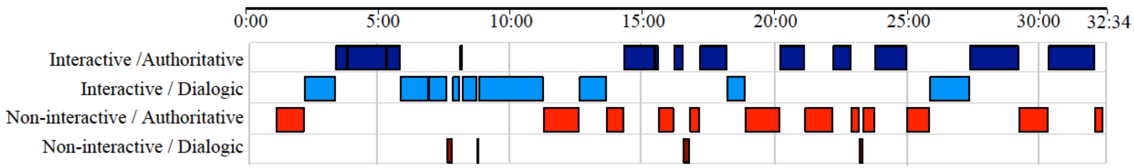


Figure 4.12. Board meeting 2, communicative approach keyword map.

The second half of the board meeting contains a much larger composition of an authoritative approach, which corresponds to the acceleration-inverse mass relationship introduction that has been discussed. During this portion, the authoritative approach is sometimes interactive and at other times non-interactive. As I expected, the transcript indicates that I was talking for longer periods of time than normal as I used the meta-data to construct plot and facilitated the unit analysis of the new graph's slope.

In addition, there were four instances in which the non-interactive/dialogic communicative approach was demonstrated. These instances occur when one person communicates various ideas of others; multiple views are shared through one voice. For example, when reviewing what had been discussed in the board meeting to that point, I stated "So you've talked about the shape of the graph being linear. You've talked about ah positive slopes. You've talked about correlations ah are strong suggesting a relationship between acceleration and unbalanced force" (BdMtg 2, 0:07:37). Although I neglected to name the various students who contributed each of these similarities, the students recognized that these ideas were determined and confirmed by members of the group. I also used this communicative approach by incorporating the idea of a single student by saying, "So you said that for us to determine if there really is a relationship that's inverse, we have to plot the slope versus the inverse of the mass, one over the mass" (BdMtg 2, 0:16:34). Whether it is several students' ideas or the idea of a single student, the non-interactive/dialogic approach is consistent with revoicing the ideas of members of the classroom community. Although grouping the students as a whole can help students take ownership of the discussion while sharing the ideas with the group, not mentioning individual student input results in a missed opportunity to improve that individual's status through revoicing.

Overall, the communicative approach keyword map is consistent with the flow of the board meeting; in the first half of the discussion, the dominant communicative approach was interactive/dialogic as students' ideas were explored. However, in the second half of the board meeting, the dominant voice was mine, and as a result the interactions revolved around an authoritative perspective. During this time, when students did contribute, the interactions were usually focused on a single perspective being facilitated by me as the instructor. In this portion, the data suggests that the interactions became less of a group discussion and more of a facilitated lecture. The dynamics of this two-part discussion are observed in other aspects of the analytical framework.

Patterns of discourse. With this board meeting, again I had hoped to have chains of interactions that would indicate students were working explain their reasoning, and I was also hoping that the students' longer experience in the class might result in more student-initiated contributions. However, I expected that the dynamics of the two-part discussion would also affected the general patterns of discourse. The keyword map for this board meeting's patterns of discourse is shown in Figure 4.13.

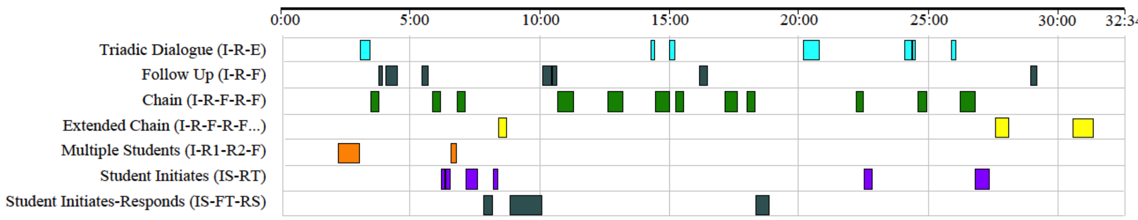


Figure 4.13. Board meeting 2, patterns of interaction keyword map.

As before, the dominant pattern of discourse was the interaction chain; for instance, I was comfortable asking students to elaborate on their thinking in this passage:

SH:	*So that being said, okay, that being said let's turn our conversation ah by talking about the similarities that you observe in the whiteboards.*
Shawn:	*Correlations are all pretty close to one.*
SH:	*What does that suggest?*
Shawn:	*That the, that the relationship between unbalanced forces and acceleration is strong.*
SH:	*Okay.*

(BdMtg 2, 0:05:52)

In this passage, the follow-up move of ‘What does that suggest?’ encouraged Shawn to describe the relationship between the unbalanced force on an object and the acceleration that it consequently experiences.

The keyword map also indicates that there are some different patterns of discourse than those observed in the first board meeting. For instance, this is the first example of student-initiated interaction patterns, such as when one student advocated for her idea of the graph shape by proposing that “the graph would be more like *y*=*x* graph” (BdMtg 2, 0:07:08). Similarly, toward the end of the discussion when we were about to begin the unit analysis for the slope of the newly constructed graph, another student said, "you end up with kilograms on top of the top fraction and that will cancel out the other kilograms" (BdMtg 2, 0:22:35). This may be indicative of a classroom climate in which students have begun to feel more comfortable speaking in class. Another different pattern observed here occurred before the formal discussion began, when one group shared a peculiar situation regarding their data:

> *Karen:* *"Well we're group 2 and um, we actually we don't feel confident in our data. As you can see it's a little bit scattered especially with our, I don't know I think it was like our point 5 or point 6. So again we can't read our board, it's unbalanced.*
>
> *Jo:* *Just like these two points down here.*
>
> *Karen:* *Ah, we can't really check them all because on here we only have like 4 or 5 points because we only got seven, so it's hard to.*
>
> (BdMtg 2, 0:02:30)

The two students spoke together to explain why they lacked confidence in their data. They had a couple data points in which similar unbalanced forces resulted in very different acceleration values, and they had not caught this until the very end of the data collection period after all equipment had been cleaned up. All students were instructed to collect ten data points, and this group was only able to collect seven, so after discarding the questionable data points they did not have enough data to suggest a pattern. It is possible that this desire to speak together was a result of them knowing that their data was going to be excluded from the class discussion, and they were demonstrating some solidarity in the fact that this was their data. Their role in the discussion changed though, in that rather than being both a data owner and data analyzer in the discussion, they were only going to be data analyzers.

Another difference in this conversation compared to the first board meeting is that the presence of triadic dialogue was considerably less than in the first board meeting, and the majority of interactions involved a follow-up move rather than an evaluative move; this might serve to signal to the students a more welcoming attitude than a judgmental one (Wells & Arauz, 2006). Finally, the keyword map shows noticeable gaps in the second half of the discussion, sparsely populated regions corresponding to the portions in which I was lecturing, and this is consistent with the presence of the non-interactive/authoritative communicative approach. Interaction patterns were limited during this portion because of there being minimal interaction.

Teacher interventions. The unusual dynamics of the board meeting can also be observed in the analysis of teacher interventions. Again, the intention of this discussion was to help students identify similarities and differences on the students' whiteboards and facilitate the formulation of Newton's Second Law, but this was the first time that I had aggregated data and manipulated that aggregated data during a group discussion. The keyword map for the board meeting's teacher interventions is shown in Figure 4.14.

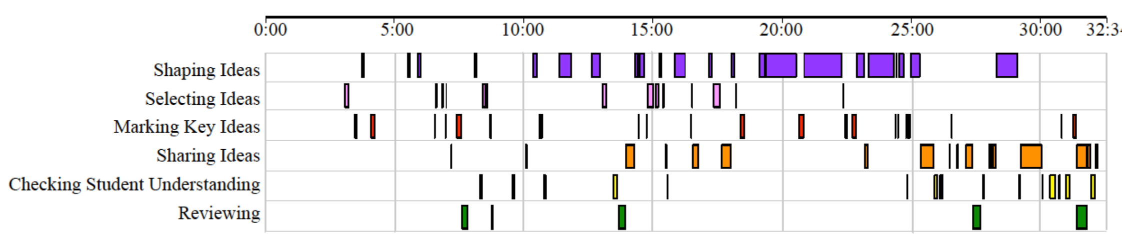


Figure 4.14. Board meeting 2, teacher interventions keyword map.

In the first half of the board meeting, there was a general progression of the interventions moving from the shaping and selecting of ideas, to the marking and sharing ideas, and then to the checking student understanding and reviewing of ideas. I began by shaping ideas by saying, “let's turn our conversation, uh, by talking about the similarities that you observe in the whiteboards” (BdMtg 2, 0:05:52). This provided scaffolding because students were specifically directed to look for similarities. Students later engaged in this exchange about the correlations of the graph:

Karri:	*The graphs are linear.*
Colin:	*Wouldn't that be directly related to correlations?*
SH:	*So how do the correlations, how does that help us evaluate linear fit?*
Colin:	*We should all have the same linear fit.*

(BdMtg 2, 0:06:40)

In my follow up to Colin’s question, I selected the portion of his statement about correlations and modified the wording to make the connection between correlation and evaluating the applied linear fit. I eventually provided a review of the key points that had been made in the discussion by saying,

> “All right so let's just summarize what we have said. We have said that as you increase the unbalanced force, the acceleration increases. That was the statement that Karri made before as well. And we've said that there is zero intercept, because like Sawyer said if there is no unbalanced force, there should be no acceleration” (BdMtg 2, 0:13:40)

Such a progression with the teacher interventions suggests that the scientific view is developed and made accessible to students in room.

However, the second half of the discussion was dominated by the intervention of shaping ideas. For instance, when discussing the new graph I plotted for the students, I said that “it's telling us that the slope of your graph is related to 1/mass” (BdMtg 2, 0:19:14). After identifying the graph’s attributes, I said, “I'm gonna put this into a form of $y = mx + b$,” (BdMtg 2, 0:19:21) in an attempt to move closer to the development of the second law. Seeing that the units for the slope were confusing, I continued, “So using your graphs, let's try to do a unit analysis here,” (BdMtg 2, 0:20:10). This sequence was a facilitated lecture of me creating a second graph and manipulating that data to establish the relationship between mass and acceleration. In this second half of the lesson, there was minimal selection of ideas or marking key ideas, simply because students did not have the opportunity to present ideas that I would select or mark. It is a stark reminder that during a lecture, student ideas are not being selected or emphasized, simply because their contributions are not present.

Although there was a presence of sharing ideas toward the end of the lesson in an attempt to make sure the scientific view was heard by all students, I already discussed with an earlier passage the scientific view was not internalized. In addition, there is minimal checking of student understanding during the lecture, so there is no means of knowing the extent to which students understood the formulation of Newton’s Second Law.

One instance occurred in the checking of student understanding that is worth examining. It happened after I had presented the relationship of Newton’s Second Law:

SH: *So where are your questions? Let's address this a little bit, what are your questions? John, what do you think?*

John: *What was the question?*

SH: *That's exactly my question. What's your question?*

John: *I don't have a question*
.
SH: *Other questions?*

(BdMtg 2, 0:25:53)

I began this passage by saying ‘So,’ and this clausal connecter assumed that after the development of the scientific relationship, students would indeed have questions. In fact, based on the nature of the content I had delivered and my experience with this lesson, I was really hoping the students had questions. Rather than waiting for someone to ask a question, I called on John. Based on his behavior already by this point in the year, I could tell by John’s body language that he didn’t know what was going on; in this instance his head had been rested on his arms, eyes closed. He asked me to repeat the question. However, rather than repeating my question in a clear manner that would give him the chance to respond, I sidestepped this opportunity and replied, ‘That’s exactly my question. What’s your question?’ This was an attempt at being lighthearted to lighten the atmosphere that was in the room; the mood was such that I felt like I trudged through the mud dragging 30 students along with me. However, for any student who was disengaged, such a response did not establish clarity but rather served as a disciplinary move to redirect the student to paying attention.

To provide some context, John was a student unlike any I had experienced before. John was the first student in my career who has fallen asleep in a board meeting. In addition, at the end of each unit in physics, we had an activity called a lab practicum, which was a lab activity in which students applied the models that have been developed to an unfamiliar situation. These activities were hands-on tasks that students typically enjoyed because they saw firsthand the predictive power of the models we developed, and they received a grade for the outcome of their solution. Every year, students have remarked how their favorite parts of the course were the lab practica. John was the only student I have taught who has ever fallen asleep during a lab practicum. I was concerned that there were family or home issues that might have influenced this behavior; I wondered if he was experiencing homelessness, or maybe dealing with other family problems. This was not the case; it turned out that John was simply disengaged. Although my instructional approach allows access to most students, it, like all instructional methods, does not guarantee the engagement of all students.

The analysis of this board meeting provides much to consider as I explore ways to introduce Newton's Second Law in the future. The labeling of this lesson as a group discussion was only accurate for the first half of the period, and reformulating the approach to introduce the relationship between mass and acceleration might be necessary if I want all students to have access to the scientific story. Tensions were present as I navigated the development of the model and wondered about the effectiveness of this particular approach; my journal entry from this discussion said how I feared "that I just dragged them along through the analysis. They answered some questions, but I do not really know what they took away from the segment. It was purely authoritative, and that was in the back of my mind the whole time" (Journal, Unit 5 BdMtg, Jan 26, 2013). Similarly, I also experienced tension in acknowledging that a student again was not engaged in my lesson. Overall, I realized that it is worth exploring other methods of introducing Newton's Second Law of motion. I now turn to the third and final board meeting being analyzed.

Board meeting 3: Projectile Motion

As a reminder, the third board meeting being analyzed was selected because of the change in pre-discussion routine in which I gave students time to share ideas in small groups before convening the large group discussion. I was interested in examining how this teacher move might affect the discourse dynamic. This final conversation was based on a laboratory experiment in which students made a video recording of two group members tossing a ball back and forth. Student groups each chose a ball of different mass, and they tossed the ball in front of a video camera in a plane perpendicular to the line of sight of the camera. The videos were imported into Logger Pro software, and the students used the software to locate the ball frame by frame in the video during its flight. Logger Pro generated graphs for the motion in both the horizontal and vertical directions, and the position versus time and velocity versus time graphs (and their corresponding equations) were analyzed and drawn on the group whiteboards.

The goal of the laboratory experiment and subsequent board meeting was to recognize that projectile motion could be modeled as two independent motions happening simultaneously: constant velocity motion occurred in the horizontal direction and constant downwardly accelerated motion occurred in the vertical direction. In fact, this unit served as a synthesis of all the units we had covered thus far in the course.

To assist in reaching the goal of recognizing the two independent motions, I tried a different strategy prior to commencing the board meeting; my journal entry following the previous board meeting discussed how students admitted that "it was not that they were uncomfortable speaking in front of their peers, but rather it was that they were not confident with the physics content of their contributions" (Journal, Unit 6 BdMtg, Jan 12, 2013). Consequently, I reminded them of the main points that we discussed whenever we have analyzed a graph: the graph's shape, the correlation of its linear fit, and the meanings and interpretations of any vertical intercept and its slope. Then, I gave them a few minutes to discuss these attributes in their small groups. I hoped that by having students first talk together in a smaller group, they would experience the "exploratory talk" (Barnes, 1976), the 'rough draft' equivalent of speech, that would give them confidence to bring their ideas and interpretations to the larger group. After several minutes of small group conversation, we began the large group board meeting.

Teaching purposes. Because I had been explicit in scientific content expectations for this conversation, I had hoped that there would be minimal time needed to open up the problem. I hoped that we could progress quickly into the exploration o student ideas and the introduction of the scientific view. The keyword map for the third board meeting's teaching purposes is shown in Figure 4.15.

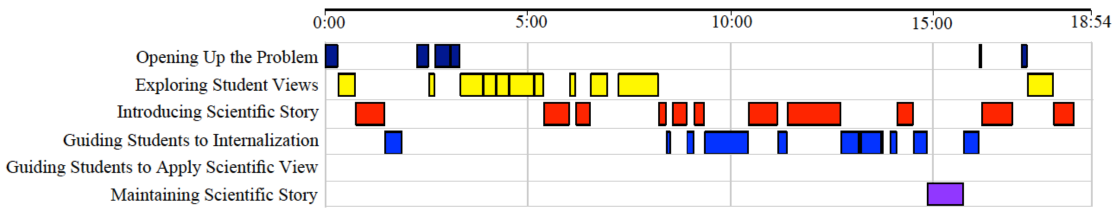


Figure 4.15. Board meeting 3, teaching purposes keyword map.

Figure 4.15 shows three 'progressions' through the teaching purposes in which the problem is opened up, students' ideas are explored, and then the scientific story is developed.

The first progression (which lasts about 2 minutes) involved me introducing the rationale for the small group exploratory talk. I opened up the problem by stating "I want to kind of get you guys thinking about some things, before we come together" (BdMtg 3, 0:00:19). Technically I was hoping the students would think and also talk before coming together, but I did not introduce it as such. I expected that students would just start sharing their ideas, and at this point in the year such expectations for group work were the norm. I continued by exploring the student ideas that had been shared regarding board meetings. Acknowledging that students had been reluctant to make contributions in the past, I reminded them of what they had told me. Specifically, "it wasn't that you felt like you were uncomfortable talking with social things you know-you weren't afraid to say something. You said, 'It was more based on in ah lack of confidence regarding the content - the physics of it.'" (BdMtg 3, 0:00:29). Consequently, I introduced the scientific story by identifying the physics content that should serve as the focus of the board meeting:

> "Now in terms of content suggestions remember what we talked about. You talk about the shape of the graphs; if they're linear you talk about the correlations to see if they are representing a strong relationship. We always talk about whether or not the intercept is important. And then finally we talk about the slopes and what the slopes mean" (BdMtg 3, 0:1:03).

This statement was an example of being explicit regarding the semantics of the scientific terms that would be used in the conversation; it was an explicit instruction in how to speak in the Discourse of being a participant in a physics board meeting. Finally, I provided an opportunity to support the internalization of these scientific concepts by saying, "take a few minutes as a group, and kind of walk through some of the content so you have a little bit of background before we come together as a large group" (BdMtg 3, 0:1:29). The use of the phrase "kind of walk through" the content was meant to indicate that this is exploratory talk, speaking in practice to rehearse ideas. It was not expected to be presentational in nature, but rather it would be an opportunity to work through interpretations and formulate statements.

The middle portion of the keyword map (minutes 3 – 16) represents the majority of the discussion, and there is considerable time spent exploring student views. For example, when asked to describe the horizontal motion first, Annie said, "they all have a positive slope" (BdMtg 3, 0:04:54) in reference to the horizontal position versus time graph. When asked what that meant in terms of the projectile, Garrett stated, "It's travelling about the same distance, in about the same amount of time" (BdMtg 3, 0:05:04). There was considerable time spent introducing the scientific view; for instance

Lorna: *All of the velocity graphs have a negative slope.*

SH: *What does that tell us?*

Lorna: *It's accelerating downwards.*

(BdMtg 3, 0:07:58)

There was also the teaching purpose of guiding students to support the internalization of that scientific view. For instance, after recognizing that most groups measured the free-fall acceleration to be slightly larger than the expected value of 9.8 m/s^2, one person proposed the possibility of air resistance being present in the lab activity. This discussion explored the affect of air resistance on an object's free-fall acceleration:

SH: *If air resistance were noticeable, how would that act on the ball if it were falling?*

Colin: *Act against gravity.*

SH: *It would act against gravity, so then how would our numbers appear in regard to 9.8?*

Boy: *Like.*

SH: *If air resistance is acting up while the ball is falling down.*

Colin: *It would be less than 9.8.*

SH: *It would less than 9.8, okay.* (BdMtg 3, 0:09:22)

This sequence used the convergent questioning format of the triadic dialogue to lead students to recognize that a falling object experiencing air resistance will have a smaller , rather than larger, value of acceleration than 9.8 m/s^2, thus providing support to guide students to internalize the measured effect of air resistance.

Looking back at the teaching purpose keyword map (Figure 4.15), this discussion did not include the teaching purpose of getting students to apply the scientific view; however, there was a portion in which the scientific story was maintained. Specifically, at the end of the discussion I made connections between this unit and each of the previous five units of the course, holding a group's whiteboard and referring to different graphs, I synthesized:

> In "unit 1, you learned how to do the graphs, right? You learn how to make graphs in in the computer. Unit 2 was constant velocity motion - that's right here, right? Unit 3 was accelerated motion - that's right here. Unit 4: balanced forces; a balanced force situation means that either no force is acting on it or the forces add up to zero. We had that happening in the first part. Horizontally there are no unbalanced forces; in this lab air resistance was not significant. When there are unbalanced forces we get acceleration like the force of gravity. We have that happening here. That was Unit 5. So, units 1, 2, 3, 4 and 5 are all put together now in Unit 6" (BdMtg 3, 0:14:51).

The synthesis maintains the scientific story that had been developed since the beginning of the physics course and it reminded students that the models that were developed in previous units were still relevant in this current unit.

This board meeting revealed a good balance of the teacher purposes; while the opening up of the problem was present, it only lasted a few minutes rather than the many minutes observed in other discussions. This could be a result of students experiencing more board meetings by this point and their familiarity with the discourse genre, students already had the opportunity to discuss their ideas in their small groups, or some combination of the two factors. In addition, the time for exploring student views was pretty defined; once the discussion introduced the student views the emphasis became introducing the scientific story and guiding students to internalization. Another observation is that this board meeting was considerably shorter in duration than the other two meetings (19 minutes for this discussion compared to the other discussions both being about 30 minutes); this could be the result of there not being the need to develop a new relationship as in the last meeting, or because the students already had discussed their ideas, or because they were more comfortable interacting with each other (this board meeting occurred in the middle of December, and students had been in the class 3.5 months by this point). However, even though the meeting was shorter than the other meetings, it was not shallow or insufficient in content. The concepts were introduced, and the horizontal and vertical motions were described and explained in terms of the forces involved. That being said, even though the meeting was relatively short, because of the nature of cognitively processing that projectile motion can be represented as two independent simultaneous motions, I did feel like I was pushing too much by including an extension question near the end of the conversation about determining the initial velocity of the projectile (this appears on the keyword map where I opened up a new problem at the end of the discussion). Overall, though, the teaching purposes demonstrated a smooth progression through the introduction and development of the scientific story.

Content of interactions: Social language. As this board meeting occurred late in the first semester, I had hoped that students would be even more comfortable participating in the discussion thus resulting in student talk being a higher percentage of the discussion. In addition, because the content of this board meeting integrated the concepts learned in previous units, I was hoping that students would recognize that those concepts were present in this motion as well and demonstrate the use of the appropriate scientific language.

The keyword map for this board meeting's social language is shown in Figure 4.16. As in the other board meetings, the most dominant form of social language present

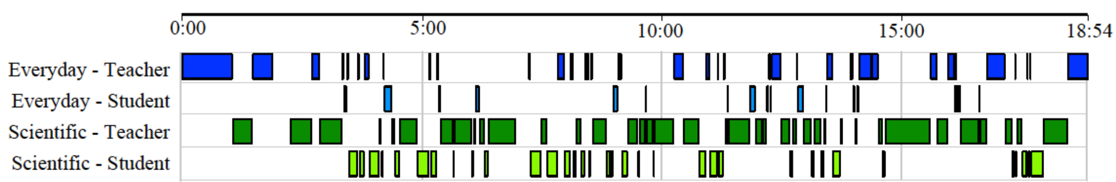


Figure 4.16. Board meeting 3, social language keyword map.

was that of me using the scientific social language. For instance, in trying to direct the conversation at one point, I stated, "Let's hone in now on just the horizontal, okay? Start your conversation about what you're seeing in those graphs" (BdMtg 3, 0:04:47). Asking for support for student responses, I asked, "is that supported? Is that consistent in the velocity graph? Do we see it generally horizontal shapes in the velocity graph?" (BdMtg 3, 0:05:47). Similarly, when trying to make sense of the interpretations that student had provided, I said, "It's accelerating downward, and what kind of accelerations were people getting?" (BdMtg 3, 0:08:13). In all of these examples, questions are posed using the scientific social language; if the scientific social language is comparable to learning another language, I need to ensure that I am providing time for the students to process what I am asking.

There were also portions of my using the everyday social language; in the beginning of the discussion as I was getting ready to begin the large group conversation I said that, “hopefully as a group you guys have had a chance to begin that conversation at your tables” (BdMtg 3, 0:02:42). In fact, the everyday social language often used to open up this problem or any problem because the intention is to make sure the directions are as clear as possible for the students. This realization creates a tension for me then, in the fact that I wonder about the extent of using the everyday social language being deliberately used in the science classroom to make sure concepts are introduced clearly too. The keyword map in Figure 4.16 shows that the everyday social language usage was pretty consistent throughout the group discussion, not only at the introduction of the conversation. Specifically, when discussing the mass of the objects and their being affected by wind, I mentioned, “Yeah it's not windy, we're not throwing, I took the Wiffle ball out. I have a Wiffle ball, but I took it out so that we wouldn't use it” (BdMtg 3, 0:12:17). Students were familiar with Wiffle balls from their physical education classes and from childhood play. Most of them have experienced the effect of the wind on a light, plastic ball with holes.

The students did not contribute a large quantity of talk using the every day social language, but they did make some contributions. Karri described the source of uncertainty in the video analysis by saying “Well, while you can't get it perfectly, because you were clicking on the object” (BdMtg 3, 0:08:59). Students actually contributed a considerable amount of talk using the scientific social language, whether it was Garrett saying the “velocity versus time graphs all have a negative slope” (BdMtg 3, 0:03:58) or when Karri proposed sources of uncertainty when she said, “Ah like if there was air resistance, or anything, or like certain way you threw the ball in the air maybe” (BdMtg 3, 0:09:10).

To consider the amount of each social language used, the time coding was extracted, and a chart of this data is shown in Figure 4.17. I contributed the largest portion of the conversation using the scientific social language; the chart shows

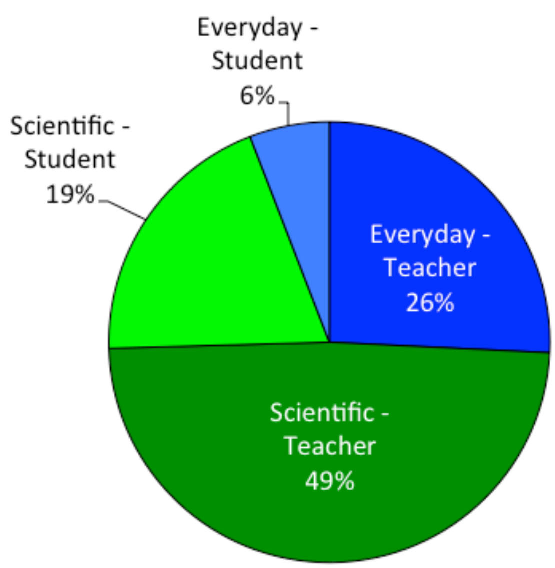


Figure 4.17. Board meeting 3, social language distribution.

it amounted to about 49% of the classroom talk. Together with my everyday social language contributions, I spoke for about 75% of the conversation. Students contributed

25% of the talk with, 19% of the contributions using the scientific social language and the remaining 6% using the everyday social language.

There are several things to note from this aspect. First, the higher rate of my use of the everyday social language (26%) is consistent with Lemke (1990) discussing how important it is for students to use colloquial language to describe concepts and also consistent with the idea of idea first, name afterward promoted by Arons (1997). There is a greater benefit to student learning when concepts are discussed in colloquial terms rather than exclusively using scientific language. However, this analysis presents two tensions in my teaching; first, I do not know how much everyday language should be incorporated compared to the scientific social language. Second, although students may be getting more comfortable practicing the use of the scientific social language, their contributions are amounting to a remarkably small percentage of the discussion. I am still dominating the conversation, and although I am attempting to foster a student-centered lesson, I still resort to teacher-moves that control the conversation. I need to consider methods that can increase student talk in the classroom.

Content of interactions. In this board meeting, I had hoped that students would provide descriptions of the projectile's motion as two independent simultaneous motions. In addition, I had hoped that students would provide explanations for those motions by performing a force analysis on the projectile in both the horizontal and vertical directions.

The keyword map for the third board meeting's content of interactions is shown in Figure 4.18.

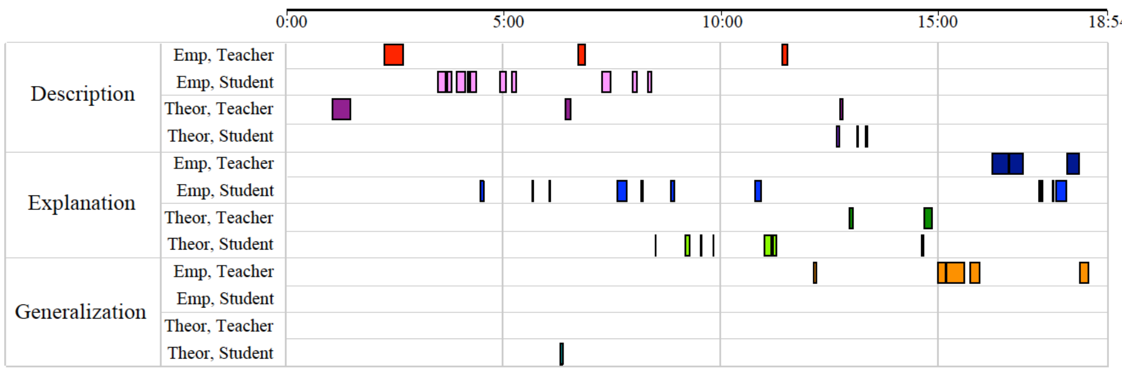


Figure 4.18. Board meeting 3, content of interactions keyword map.

There seems to be a general pattern to the content of interactions from this board meeting. Unlike the other board meetings, which seem to show a somewhat random scattering of the content descriptors, this discussion almost seems like there is a trend slanting downward and to the right; this would indicate a movement from the first level of content (description) into explanation and generalization as time progressed in the conversation, and since a goal of making models is to move from the specific to the general, this progression would be good. Early in the discussion, one student noticed a similarity among the whiteboards and described how the "Velocity versus time graphs all have a negative slope" (BdMtg 3, 0:03:58). When asked about why the ball seemed to move with a constant horizontal velocity, Moe explained, "As soon as it leaves your hand nothing other than gravity is affecting the ball, so it's gonna move at constant speed" (BdMtg 3, 0:11:11). Later, when asked about why there appeared to be acceleration in the vertical direction, Tom simply explained, "Because gravity was acting on the object" (BdMtg 3, 0:08:29). When asked about the effect of air resistance on the horizontal position versus time graph, Tom also said, it would be curved "because it wouldn't be going as far as quickly - it'd be going slower" (BdMtg 3, 0:12:51). The students did correctly explain how forces would interact with the projectile.

There were also a few generalizations in this discussion; I made generalizations when I said, "the air resistance isn't that big of a deal for these balls at these speeds" (BdMtg 3, 0:12:07). This was an empirical generalization because I was referring to the specific balls that were used in the lab. In addition, in discussing the technique of video analysis and its inherent uncertainty in clicking on an object frame-by-frame, one student generalized how "plotting points is not an exact science when you're clicking on an image." (BdMtg 3, 0:06:18). Overall, students made a variety of contributions that were both empirical and theoretical, but they did not make any generalizations about projectiles or projectile motion. Scaffolding to be more deliberate about the inclusion of such statements might be necessary to promote these kinds of statements in the classroom.

Communicative approach. For the third board meeting being analyzed, I wanted students to participate fully in the exchange by providing them the opportunity for interactivity. The keyword map for the third board meeting's communicative approach is shown in Figure 4.19.

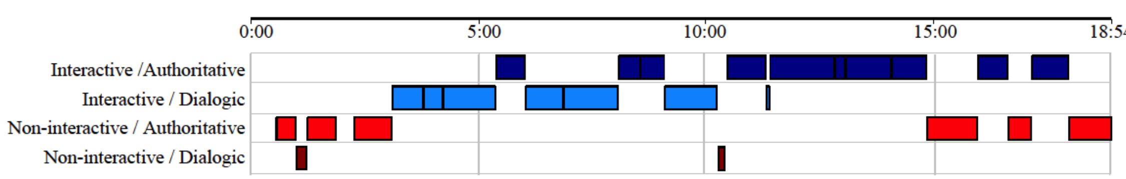


Figure 4.19. Board meeting 3, communicative approach keyword map.

The introduction of the initial small group task contained a small segment of a non-interactive/dialogic communicative approach because I reminded them about their stated reason for not contributing in board meetings. Specifically, I said, “it wasn't that you felt like you were uncomfortable talking - with the social things you know - you weren't afraid to say something. You said, ‘It was more based on a lack of confidence regarding the content - the physics of it’” (BdMtg 3, 0:00:29).

After reminding students of procedural norms and behavioral expectations, the majority of the discussion was interactive. This interactive portion was roughly divided into two halves; the first half being was mostly interactive/dialogic, with exchanges such as this:

SH: *Talk about the vertical position in velocity graphs.*

Sawyer: *The parabolic shape of the curve shows that it has a change in height, and that is the distance we measured.*

SH: *Okay*

(BdMtg 3, 0:07:29)

Sawyer addressed the shape of the vertical position versus time graph and incorporates the mathematics descriptor, parabolic. An interactive/dialogic approach was also demonstrated when Garrett discussed uncertainty in the analysis:

SH: *So then why are we getting that scatter?*

Garrett: *Plotting points is not an exact science, when you're clicking on an image.*

SH: *What do you think about that explanation?*

(BdMtg 3, 0:06:11)

The question I posed to the group after Garrett’s response was not directed to any particular person, so although several students nodded in agreement with Garrett’s response, there was not an identified student asked to respond. Questions such as this that are posed to undetermined students provide little information about what the students understand unless the students are specifically selected.

The second half of the discussion was interactive/authoritative. For example, when discussing the effect of air resistance on the shape of the horizontal position versus time graph:

> *SH: If we wanted to really see you know air resistance and you did a ping pong ball, how would your position and the velocity graphs change for the horizontal?*
>
> *Tom: The position graph would be curved.*
>
> *SH: The position graph would have a curve. It wouldn't be a line anymore* (BdMtg 3, 0:12:30)

This interactive/authoritative example introduces the scientific view about the graph of an object experiencing air resistance. Overall, the division of the interactive/dialogic and the interactive/authoritative approaches is consistent with the exploration of student ideas at the beginning followed by the facilitation of the scientific story introduction in the second portion.

There was only one instance of the non-interactive/dialogic communicative approach; this example occurred early in the discussion after a student had proposed two possibilities for the uncertainty that we were observing in our data, and after we discussed both of them I said “I think the first thing you said Karri, clicking on the points is probably the reason. I think that that's right on the money there, okay?” (BdMtg 3, 0:10:16).

The general flow of this communicative approach in this discussion resonates well with me; it makes sense that the beginning portion would involve the setting of the stage and would therefore be non-interactive/authoritative. Student ideas would be elicited to start the focus of the discussion, and that would be the interactive/dialogic approach. To introduce the scientific story, I needed to facilitate the discussion to incorporate student ideas but also work towards the scientific view. To extend the student's thinking, there is a small sequence of the same flow at the end of the discussion, when I introduced the question about determining the initial velocity of the projectile based on the horizontal and vertical components of the velocity. However, as I discussed earlier, that extension might have been more effective after students processed the main concepts from the conversation. I think that a weakness of this particular board meeting was the lack of a substantive non-interactive/dialogic approach. Once students returned to their seats, I wrote out on the board a summary of the key points that students made during the discussion, but there would have been value in emphasizing which particular students contributed specific points to the discussion by using the revoicing move; such a move could have improved the status of any students who contributed remarks in the discussion.

Patterns of discourse. In this board meeting, I again had hoped to demonstrate chains of interaction. Although I had not considered it explicitly, I ultimately would have liked students to initiate more of the conversation and even bring up questions. The keyword map for the board meeting's patterns of discourse is shown in Figure 4.20.

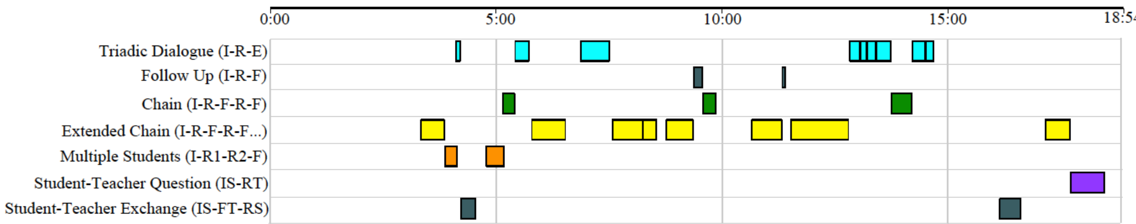


Figure 4.20. Board meeting 3, patterns of discourse keyword map.

The patterns of discourse keyword map appears unpredictable. The dominant pattern of interaction for this discussion is the extended chain, which demonstrates that either the question type was more open-ended or the follow-up moves were less evaluative and more about seeking information from students. Transcripts indicate that is was more often the latter. For instance, consider this exchange when students started describing the appearance of the graphs:

SH: *Do we see it - generally horizontal shapes in the velocity graph?*

Sawyer: *With the line of best fit, yeah.*

SH: *With the line of best fit, why did you qualify that?*

Sawyer: *Ah because you know it's got the fun little ridges going on there too.*

SH: *Do the other people see like that scattering of the points? So then why are we getting that scatter?*

Garrett: *Plotting points is not an exact science, when you're clicking on an image.*

SH: *What do you think about that explanation?*

(BdMtg 3, 0:05:47)

The flow of this episode is more conversational in tone, beginning with me asking Sawyer why he qualified his statement; rather than simply saying ‘yes,’ he said “with the line of best fit, yeah." He responded without delay, and the tone continued to be informal as indicated not only by his colloquial use of the 'because you know' to indicate familiarity, but also because his remark of the 'fun little ridges' occurring there communicates an emotive response. As Lemke (1990) states, science instructors teaching about the stylistic norms of scientific writing often require students to avoid metaphoric or figurative language, resulting in "a recipe for dull alienating language" (p. 134). Sawyer's colloquial language is comfortable, and although I do not repeat his phrasing and instead use the word 'scattered,' I was not opposed to his interjecting a word more closely related to human emotion. Overall, I am pleased with the extent of these longer interaction chains because they indicate that I am providing students with the opportunity to explain their reasoning or clarify their statements.

Considering other patterns of discourse in this meeting, triadic dialogue was still present, but the keyword map indicates that it was less pervasive than in earlier board meetings. In addition, this discussion also incorporated some student-initiated questions, which is different from the other white board meetings that have been analyzed. I am happy that students felt comfortable to ask questions in this discussion; in many of the earlier discussions I initiated the interactions, and if I am interested in students improving their sense-making through this discourse then they need to feel comfortable working on ideas and asking questions.

Teacher interventions. Similar to the other board meetings, I expected that the mapping of teacher interventions would demonstrate a flow from the shaping and selecting of ideas to the checking of student understanding and reviewing. This board meeting lent itself to reviewing not only concepts from the conversation but also concepts from previous units, because the scientific content incorporates key ideas from every unit earlier in the year.

The keyword map for the board meeting's teacher interventions is shown in Figure 4.21.

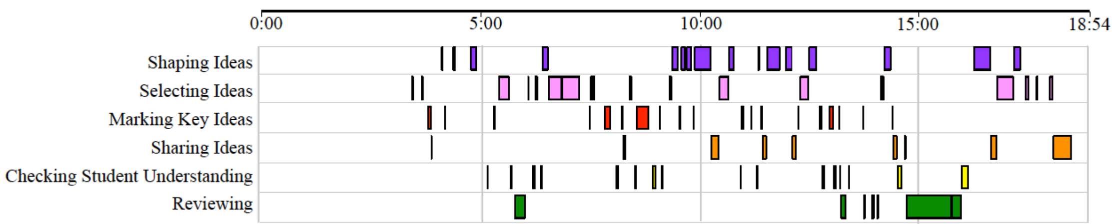


Figure 4.21. Board meeting 3, teacher interventions keyword map.

In examining the keyword map, it appears that there is a slight progression in the teacher interventions from the shaping and selecting of ideas at the start to the reviewing towards the end of the discussion. This board meeting involved an interesting use of the selecting ideas teacher intervention; the example begins when I asked the students about the values they obtained for the projectile's vertical acceleration due to gravity:

Teacher: *Why are they not exactly 9.8?*

Karri: *Video analysis, and other things acting on the object.*

Teacher: *You said video analysis; tell us more about that.*

Karri: *Well, while you can't get it perfectly, because you were clicking on the object.*

Teacher: *Okay.*

Karri: *You can make mistakes there.*

Teacher: *And then you said other things acting on it. Tell us what you meant by that?*

Karri: *Ah like if there was air resistance, or anything, or like certain way you threw the ball in the air maybe.*

Teacher: *Okay, let's talk about air resistance. I think that's a good thing to discuss. If air resistance were noticeable, how would that act on the ball if it were falling?*

(BdMtg 3, 0:09:06)

This portion of dialogue begins with the student giving multiple answers to my first question. I selected one of her answers by repeating it, and then I asked her to elaborate on that portion of her answer. She correctly identified the uncertainty introduced when trying to click on an object when performing video-based motion analysis. Next, I selected the second portion of her original response, when she said other things were acting on the object, and I asked for her elaboration there. She responded by giving two answers again, first saying air resistance and then the way the ball was thrown. I agreed with her but selected one idea, air resistance, again. The topic of air resistance was worthwhile to discuss, because students inevitably will introduce it at some point. However, because of time I omitted addressing the second portion of her response when she discussed the manner in which the ball was thrown (I had intended to return to this point but forgot and never addressed it). The reviewing of earlier units is prominent toward the end of the discussion as indicated by the large segment in the bottom band. In addition, the intervention of checking student understanding appeared at a pretty consistent spacing throughout the discussion.

There is value in having the reviewing section at the end of a discussion, it is a way to make the talk tat has occurred more formalized, and it might provide an authoritative voice to the important points in the conversation. Such timing can leave an impression on the students as a closing or final thought. This is related to the earlier statements in which I realized I should have ended the discussion and asked extension questions after there was time for students to internalize the findings from this discussion.

I now turn to the analysis of the graded discussion speech genre. Because of the lessons' similar structure, the two graded discussions are presented together. After introducing the intention and the physics topics involved in the lessons, I discuss the two conversations according to each aspect of the analytical framework. The two lessons' keyword maps for each aspect of the analytical framework are introduced and discussed by first comparing my intent of the lesson with how it actually unfolded.

Graded Discussions

My intention in conducting graded discussions was to provide a space in which as many students could make their voice heard. Early in my educational training I had learned about Freire's (1970) critique of the banking model of education, a passive system in which teachers deposited information into students and then withdrew that information from the students during exams. I was more attracted to Freire's (1970) model of teaching as mining, a system consistent with constructivist pedagogy in which the teacher's role was to pull existing knowledge out of students and make sense of it in a new context. I considered the graded discussions as a place where I could extract student thinking and help them make sense of these particular physics phenomena.

Physics lessons. The first graded discussion occurred in the second month of school during the unit exploring accelerated motion. I chose to analyze this lesson because I was interested in exploring the extent to which my facilitation provided space for students to share their ideas. In the class period prior to this discussion, students had observed a series of interactive lecture demonstrations involving a cart traveling down or up a ramp. Students observed several examples of the cart moving in one direction only (up or down the ramp) with a motion detector in various locations (at the bottom or top of the track), and they were asked to predict the position versus time and velocity versus time graphs for these demonstrations. The cart's position and velocity were then measured in real time using the motion detector, computer data interface, and Logger Pro software, and the graphs were then discussed. For the first graded discussion being analyzed, students were shown the motion of the cart being given a quick push up the ramp and then released, such that it traveled up and then down the ramp before being caught. The motion sensor was located at the bottom of the track. As shown in Figure 4.22, students were shown a prompt asking them to predict and draw the position versus time and the velocity versus time graphs that would represent the motion after the initial push and before the final catch. In addition, after completing their prediction graphs, students were given several minutes to discuss their predictions in their small groups before the start of the graded conversation.

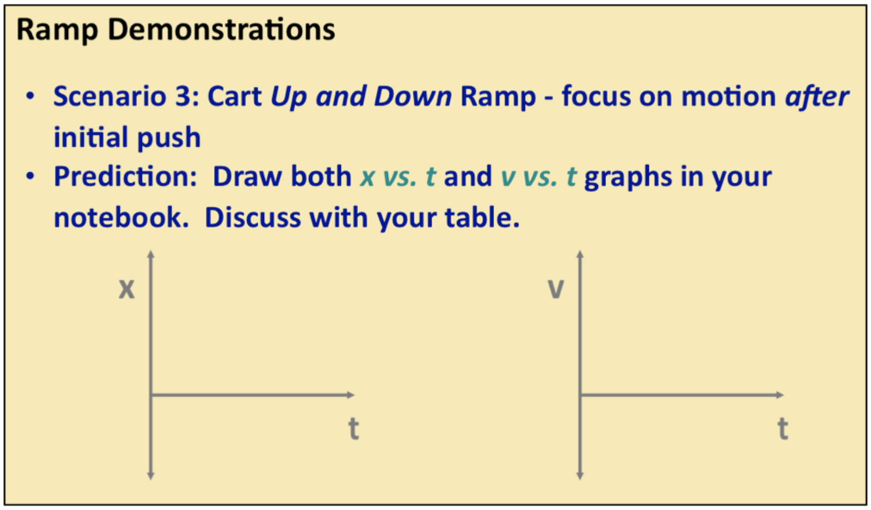


Figure 4.22. Student prompt for graded discussion 1.

The second graded discussion occurred in the second semester of the school year during a unit on direct current electric circuits. Because the discussion happened in the second semester, the student make-up of the class was slightly different than the same class period from the first semester, but I was interested in analyzing that discussion because I wanted to examine how I facilitated another opportunity to provide a space for student voice during a ranking task activity. Specifically, students were asked to rank the total resistance of some electric circuit networks. The ranking task was taken from *Tutorials in Introductory Physics* (McDermott and Shaffer, 2002), and is shown in Figure 4.23. The problem had been assigned as a homework exercise prior to the graded discussion, and as with the first graded discussion, students were given several minutes to discuss ideas with their small group prior to the start of the large group graded conversation.

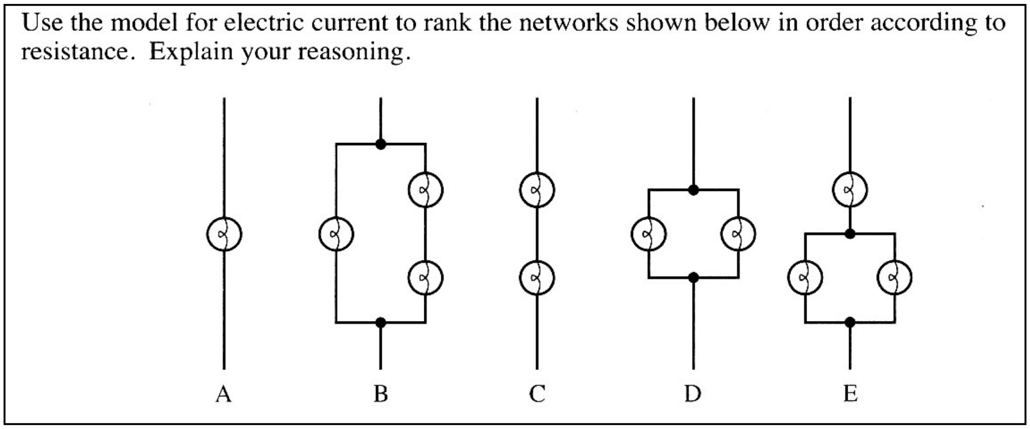
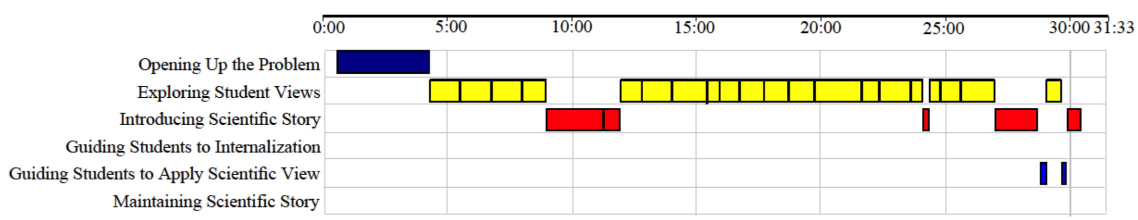


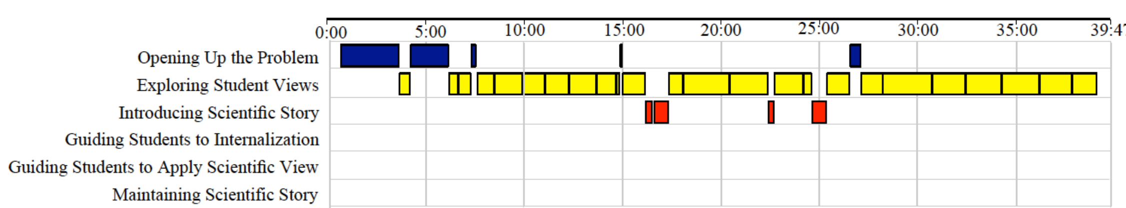
Figure 4.23. Student prompt for graded discussion 2.

Teaching Purposes. My intention for conducting graded discussions was to encourage as many students as possible to contribute to the classroom conversation. In addition, I wanted students to wrestle with the ideas presented by their peers and interact with one another in a conversation rather than have students list a series of unrelated statements.

The keyword maps for the graded discussions' teaching purposes are shown in Figure 4.24.



(a)



(b)

Figure 4.24. Teaching purposes keyword maps for graded discussion 1 (a) and graded discussion 2 (b).

Both discussions involved a beginning portion in which the teaching purpose was opening up the problem. Because the students had never experienced a graded discussion in this physics class, I began by introducing the norms and expectations for what it meant to be a participant in the graded discussion. I first identified the types of possible contributions by saying,

> "there are really three ways that you can contribute to this: answering a question that either I ask, or one of your peers asks; asking a question, which can be a tremendously important thing - the breakthrough moment in the last period's conversation happened from a student question, okay; finally making a clarifying statement." (GD 1, 0:01:00).

I elaborated on what I meant by clarifying statement by saying that it might not necessarily introduce new content but rather "restate what's been said" (GD 1, 0:01:27). I spent time discussing these specific contribution types to clearly communicate my expectations for the student's use of voice; as I described this student population earlier, they are academically strong, but like all students they appreciate knowing how they will be assessed. I finished this segment by sharing behaviors that were expected but not assessed; for instance, I said, "notice I don't have 'paying attention,' I don't have 'no side conversations,' those are things that I'm expecting at this point" (GD 1, 0:01:50). In this manner, students were explicitly told to pay attention and not engage others in side conversations during the discussion. I then mentioned to the students that simply stating an answer might not be sufficient; I told them I might "be asking that you substantiate your claims - Why are you saying that? So if you come up with a shape that you wanna propose, tell us *why* you think that is, okay?" (GD 1, 0:02:13). This is related to Toulmin's (1958) framework for argumentation in that using data, students make a claim that they then substantiate with warrants.

After introducing the norms and expectations for content and behaviors, I talked about how I would keep track of each student's contributions; I told them "I'm gonna be just making a tally mark here on the seating chart, so that I know that you contributed" (GD 1, 0:02:42). However, to encourage self-tallying I said, "as a back up, what I'm asking you to do is hold your hand when you wanna contribute, and give me a sign to show how many times you've spoken" (GD 1, 0:02:50). Students were shown to hold up one, two, three fingers, etc., and then to be very clear regarding the selection of contributors, I told them if two people want to speak to the same point, "I'm gonna call on the person with the lower number to get as many voices in the conversation as possible" (GD 1, 0:03:15). The quality of each contribution was not assessed, but rather as long as it fit into the three categories mentioned earlier the student received credit.

Finally, to assist in developing conversational aspects to the discussion, I considered it necessary to encourage students to listen to one another - especially if a classmate was asking a question. Specifically, "if somebody asks a question, I'm gonna put the brakes on other peoples' comments and I'll say, 'Who can speak to that question?' so that it can flow. This should be a conversation that has a nice flow to it as opposed to just random blurts of facts" (GD 1, 0:03:48). I was explicit with this instruction because in the past I have had graded discussions in which students were so focused on introducing their ideas that they did not acknowledge the student who had just asked a question to the class; in these cases the question poser has been cast as an outsider and it negatively alters the dynamic of the discussion. All of these comments, then, from the contribution type to the logistics of tallying were intended to clearly communicate the Discourse of being a participant in a graded discussion; similar comments were made in my introduction to the second graded discussion regarding contribution type, tallying, and conversational flow.

Examining Figure 4.24 parts (a) and (b), there is a beginning teaching purpose of opening up the problem, and then the keyword maps indicate that student views were being explored; in fact, the dominant band in each discussion represents the exploration of student views. In the first discussion, students contributed their predicted graph shapes, such as when Mallory said, “we had it so it kinda like plateaus at the top, ‘cause it like pauses for a second, so it goes in a straight line and slants” (GD 1, 0:04:45). Another student presented a challenge to a graph shape proposed earlier; Jill commented, “I don't like the U shape, because now that camera thing is down at the bottom that's not considered the origin” (GD 1, 0:08:02); she referenced the motion sensor and the effect its location had on the location of the origin. Even later in the discussion students were still proposing different shapes, such as when Colin proposed, “shouldn't it be more like a lightning bolt almost? ‘Cause you increase in velocity, then you slow down a little bit - you know when it's changing - and then it increases again because it's going back down” (GD 1, 0:20:47). Interestingly, the correct answer for the velocity graph was not proposed until 21 minutes into the discussion when Tom said, “I wanna say that it could be just a straight line and starting a little bit up on the velocity, and then go negative, ‘cause some point the velocity has to be negative" (GD 1, 0:21:55). There was certainly ample opportunity for students to share their views in the cart and ramp discussion.

In the second graded discussion, the dominant band in the teaching purposes keyword map was also the exploration of student ideas. Students proposed the ranking positions of different circuits, and other students challenged the proposed positions of the circuits, such as when Lia said, "I don't think A goes there - I don't where it goes - because you talked about yesterday, the more parallels that there are the less resistance there is. So I don't think A would go in that spot. I think the parallel circuits will go before that" (GD 2, 0:09:33). In this example, Lia is connecting her claim to an earlier lesson and trying to use the data from that experiment as a warrant. She doesn't propose to be an information provider because she interjects that she doesn't know where it should go, but she believes its current location was incorrect. Other students supported their claims as well, such as when Dylan said, "Because ah E has parallel circuit which means it's going to be drawing more voltage from the battery. And A is just a single bulb, so it's not gonna take that much energy from the battery" (GD 2, 0:20:47). Although he incorrectly used some terminology in his statements, he was trying to substantiate his claim for the argument. Overall, my tallying indicated 24 out of the 30 students in attendance contributed to the first discussion and 24 of 31 students in attendance made contributions in the second graded discussion. This suggests that students generally were able to find a space for their voice in the class discussions.

However, the maps in Figure 4.24 also indicate that although many students' views were explored in the discussions, there were limited instances of other teaching purposes. For instance, in the first graded discussion the scientific story was introduced during a portion of the conversation in which students were questioning the location of the origin in relation to the motion detector. Then, the scientific story was also introduced toward the end of the discussion after actually running the cart and collecting position versus time and velocity versus time data. This occurred near the end of the class period after I stated, “we've only got five minutes left. I think what might be good for us, is to run it” (GD 1, 0:26:20). Before collecting the data, in an attempt to maintain student focus, I stated, “Now the discussion isn't finished when I run this because there's a couple questions that I wanna ask you” (GD 1, 0:26:59). The position versus time and velocity versus time graphs were generated and projected for the students to see.

In retrospect, five minutes was not nearly enough time to provide students the opportunity to see the data that had been collected and begin making sense of it. The introduction to the scientific story included me indicating to the students where to look on the position versus time graph by saying “our region of interest is in here” (GD 1, 0:27:20). Then, the guidance that I provided to support the internalization of the scientific story consisted of this interaction that responds to my request asking students to eliminate any of our predictions:

> *Sam:* *Well it's because for the upside down V one it's just speeding up and then slowing down. And then for the normal V it's just slowing down and then speeding up.*
>
> *SH:* *Whereas.*
>
> *Sam:* *Whereas the one that's correct it's just slowing down and then speeding up it's at a negative rate.*
>
> *SH:* *Okay* (GD 1, 0:28:41)

Because this exchange happened in the waning moments of class, students were just introduced to the scientific view and were given minimal support to begin internalizing what the graphs actually showed. Consequently, if learning is seen as the process of *internalization* (Vygotsky, 1978), the movement from social to individual, in which the individual plane is formed, then this first graded discussion did not provide much opportunity for learning because it lacked the opportunity for supporting internalization. Moreover, there were no instances of applying the scientific view to another situation or maintaining the scientific view.

The teaching purposes keyword map (Figure 4.24b) shows a similar pattern for the second graded discussion; the second discussion also began with a segment opening up the problem, such as when I said:

> "With the graded group discussion, you are going to be graded based on the contributions that you make. I want to remind you that just paying attention is not enough. Paying attention is expected, okay. Since it's a discussion, it's only those contributions that I can really tell and really assess you on" (GD 2, 0:01:00).

Once the discussion began it was dominated by the exploration of student views. For example, Jack described one predicted position by saying, "I think E would be the 3rd least resistant, because um the electricity has to go through the first bulb and then it splits" (GD 2, 0:09:11). Likewise, Trevor answered a student's question by saying, "since um they're set up in parallel there is gonna be the same amount of current going through each bulb as in A, but since there's two loops, there's gonna be twice the current" (GD 2, 0:13:58).

However, during the second graded discussion, there were only slight instances in which elements of the scientific story were introduced. In this exchange, Karri discusses what differentiates series from parallel circuits:

Karri: *Isn't a series when ah the current goes through the first bulb but also has to go to the second one too.*

SH: *So would you say that both of these are in series?*

Karri: *Um, I would say no, I would say that the first, or the second one B has a series on the right side.*

SH: *Okay.* (GD 2, 0:16:38)

In this example we clarified how to think about the arrangement of the bulbs in the circuits, and this distinction played a key role in understand the different circuit behaviors. Later in the discussion the scientific story is introduced through the use of an analogy:

Ciera: *Like the hallway like over there how some people keep going straight and some people go that way `cause there's less people. So if there's more paths, there's least resistance `cause more, there's more current.*

SH: *Yeah why can you get more people, why can you get more people down the hallway if you open up another path.*

Ciera: *Because more people are gonna move the way where there's not much.*

SH: *Yeah so people choose the freer space, the more open space, that will allow a greater number of people to actually get through.* (GD 2, 0:24:41)

Through this exchange, the analogy of students traveling through the school's halls is used to better understand the movement of charges in a circuit.

Near the end of the second graded discussion, I decided to provide a space for those students who had not made their voice heard; specifically, I provided an option for any student who disagreed with the class's circuit ranking to write out their individual rankings and submit them the following day. As a result, the discussion ended without any considerable introduction of the scientific story because the correct rankings were not revealed until the following day. The major consequence of this decision was that there was not an option of guiding students to internalize the scientific story, and therefore a formal opportunity for making meaning was lost. I returned to the ranking exercise and provided the correct order the next day, but the momentum from the previous day was lost; in addition, we had not documented the reasons for the ranking as we had them, so it was difficult to ascertain on the next day what students remembered about the discussion.

If my goal in these graded discussions was simply to hear from as many students as possible in a forum in which students' ideas could be shared and explored, then that goal was achieved. In retrospect, however, the ultimate goal of the discussion strategy should have been to elicit student ideas, and then develop and internalize the scientific story; it is during the internalization phase that student learning occurs. In neither of these discussions, then, would I consider the lesson successful. In the first discussion in which the cart traveled up and down the ramp, data was collected and students could see the correct shapes of the position versus time and the velocity versus time graphs. However, without a more deliberate and thorough analysis of those generated graphs, the introduction to the scientific story is minimal. Moreover, without the time to ask meaningful questions encouraging students to interpret the data, then the learning resulting from this discussion was minimal. The first graded discussion involved the major misconception about an object's acceleration when it is at the peak of its motion (Hestenes, Wells, & Swackhamer, 1992). Mortimer and Scott (2003) mention that if there is a large learning demand (such as a major misconception), then students should have a considerable opportunity to discuss the ideas to make sense of them. Students did not have an opportunity to discuss the cart's acceleration at the top of the ramp in the graded discussion.

As with the first example, in the second discussion many student voices were heard and their ideas were explored. Knowing that some students might still be reluctant to participate verbally in class, I decided to provide the students who did not speak an opportunity to consider the class circuit ranking solution and propose a different ranking if they did not agree with the class results. By choosing to give them this option, I forfeited the chance to communicate the correct rankings to the class and the subsequent opportunity to make sense of those rankings. In fact, the keyword map shows how the last 14 minutes only involved the exploration of student ideas; not only was there no development of the scientific story, the majority of students had no formal chance to internalize the findings and learn from them. Some students might have internalized the strengths or weaknesses of the other students' ideas, but I did not provide any formative assessment to measure their understanding. I imagine that if I were in the students' seats during this portion of the discussion I might feel that as a class we were simply spinning our wheels, without an opportunity to make sense of what was happening.

Content of Interactions: Social Language. As I mentioned, the graded discussions were intended to give the opportunity for students to voice their ideas regarding a specific physics problem. Moreover, I wanted students to have a formal opportunity to practice using the language of physics in a familiar setting. I served as facilitator for the discussions to promote a space for as many voices as possible and to avoid my perceived potential favoritism of student facilitators.

The keyword maps for the graded discussions' social language are shown in Figure 4.25, and graphs of the extracted time code data for the graded discussions are shown in Figure 4.26.

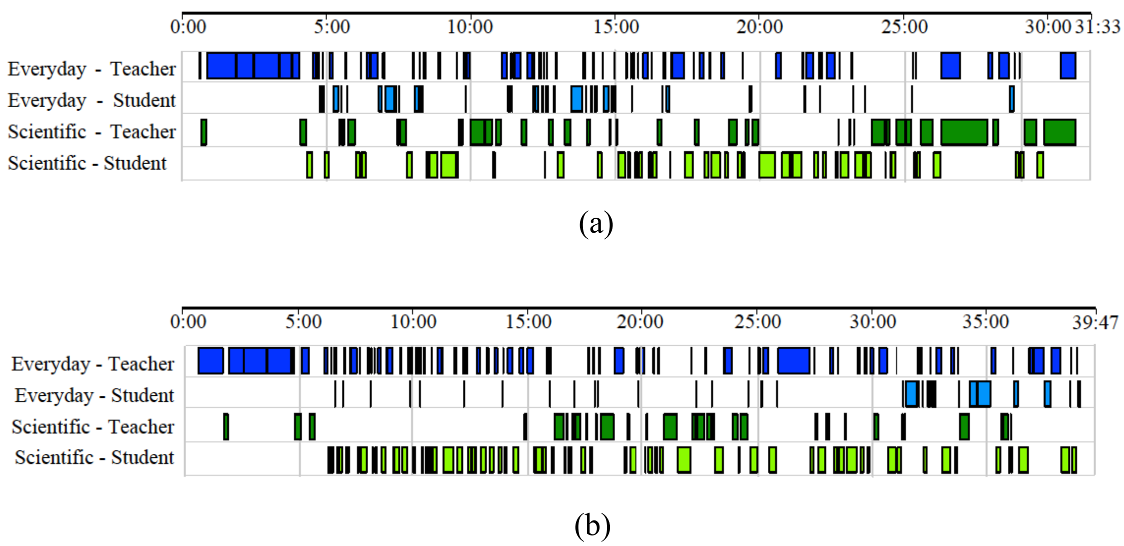
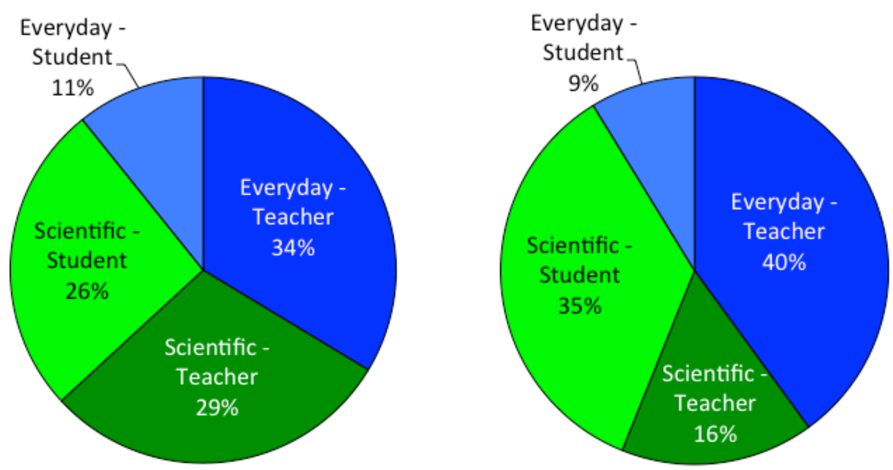


Figure 4.25. Social language keyword maps for graded discussion 1 (a) and graded discussion 2 (b).



(a) (b)

Figure 4.26. Social language distributions for graded discussion 1 (a) and graded discussion 2 (b).

As the teacher, I had a very strong presence in the discussions, with my contributions amounting to about 63% of the first graded discussion and 56% of the second discussion. In both instances, I demonstrate more everyday social language than scientific social language. Student voices demonstrated the scientific social language was about 26% of the first discussion and 35% of the second.

The distribution of social language usage was different in the two discussions. In the first discussion, both social languages were used by the students and instructor for the first half of the conversation. For instance, when describing the predicted graph, one student said, “Ours was similar but it had um more of ah angle, so this is like a curve for the whole thing is more like straight, and then curve at the top, and then straight again” (GD 1, 0:05:13). Students also used the scientific social language, such as when asking about the relationship between the sensor and the graph’s origin, one student said “are we starting to register the points after the push, and in which case the point in which the push was made was the origin?” (GD 1, 0:09:13). I used the everyday social language when a student proposed that the graphs be shifted, I followed up by saying, “I'm gonna move the green one up, because that's the one that that Moe picked. But do people understand what he's proposing, that any of them should be up and out?" (GD 1, 0:06:30). I did not mention the origin or the effect of creating an intercept that such a shift introduces. I did use the scientific social language when I initiated the conversation by asking, "who would like to start off proposing predicted shapes for position versus time or velocity versus time?" (GD 1, 0:04:04); the first comment of the discussion portion involved the scientific social language.

However, in the second half of that discussion, students frequently demonstrated the scientific social language (minutes 15 to 24), such as when Jason proposed that there should be a portion in the negative region of the velocity graph by saying, "wouldn't it have to like be, on the negative point of the velocity at some point" (GD 1, 0:17:26). Likewise, Lillian engaged in the scientific social language when she addressed the difference between decreasing velocity and negative velocity by saying, "I think there's a difference because deceasing means that um, like it's um, going like the numbers are really going down, but negative doesn't necessarily mean that. It just means that like the slope is, ah the slope is negative" (GD 1, 0:19:59).

My use of the scientific social language dominated the conversation from minutes 24-31; for example, when trying to clarify what one student asked, I said, "Do understand what he's saying? He's saying if this is the graph, is this saying that the cart, uh, reaches the origin and goes past the origin off the track this way?" (GD 1, 0:24:50). Later, I corrected a student when I said, "this is the velocity graph, so these are saying that it speeds up, and then slows down but all in the positive direction" (GD 1, 0:29:14). The scientific social language was certainly present.

In the second discussion, students used the scientific social language consistently from minutes 6-34 and mostly the everyday social language from minute 34 until the end. For example, in describing the behavior of a circuit containing two bulbs, Sawyer stated, "well it's a it's a single current moving through that series circuit there. And because of the two bulbs I think that will hinder it the most" (GD 2, 0:07:43). His use of the words 'current' and 'series circuit' resulted in this comment being coded as the scientific social language, but it is interesting that he used the phrase 'will hinder it the most' compared to the phrase 'have more resistance,' which would have been more scientific. Later, Ciera asked, "Um, weren't like, when we like set up a parallel one in a single circuit weren't their brightnesses like the same? Why would A be second in resistance, if D and A had the same brightness?" (GD 2, 0:12:56). She referred to the experiment that had been conducted earlier in the unit in which the students constructed simple series and simple parallel circuits, so she was actually serving to share the scientific language from an experience that was common to her peers. Students used the everyday social language from minute 34 until the end of the discussion, such as when Shawn justified his claim by stating "with A you just have to go through one and B you can choose between going through one or two. But with E you have to go through two no, no matter what path you take" (GD 2, 0:31:29). Overall, students contributed in both social languages.

Although student voices were more present in these discussions than the board meetings, I was still surprised at the amount of talking that I did in the graded discussions. Only in the second graded discussion, the latest in the year of all classroom discussions analyzed, did my contributions amount to less that 60% of all classroom talk. While I was initially pleased to observe my lower contribution percentage, I then realized those numbers would have changed if the exploration of student ideas ended earlier and the scientific view was introduced; because of the complexity of the task, I might have needed to use questioning techniques to formally arrive at the correct ranking, thus increasing my contribution percentage.

I was most pleased with the presence of students demonstrating the scientific social language; in the second discussion, students used the scientific social language about one-third of the time. Part of that increase in the use of the scientific social language is related to the physics content of the discussion; the first graded discussion was analyzing a cart traveling up and down a ramp, which could involve students saying non-scientific descriptors such as up, down, speed up, etc. However, the second graded discussion involved ranking circuit networks in terms of their total resistance, and this discussion relied on the incorporation of concepts like electrical current flow and electrical resistance; there were not as many colloquial words that students could use in the discussion.

Overall, then, as long as I serve as facilitator of these graded discussions, it seems that it would be unlikely to conduct a discussion in which I spoke less than 60% of the class period. While my initial goal in graded discussions of including as many student voices as possible may have been worthy, this research indicates that structural changes are necessary to ensure that students not only contribute but can make meaning from the scientific story that the discussion entails.

Content of Interactions. The nature of the physics content in each graded discussion affected not only the social language but also the content of the interactions. Specifically, the physics lesson for the first graded discussion required students to predict the shape of the position versus time and velocity versus time graphs for the cart traveling up and down the ramp. I expected both the description of those predictions and the explanations for those predictions from the students as the discussion progressed. Both of these statement types would tend to be empirical in nature because the motion of the cart had been observed prior to the discussion. In the second discussion, I expected students to address the concept of total resistance and describe the various circuits as being connected in series, parallel, or some combination of series and parallel. I also expected them to provide explanations for their proposed ideas. Because they did not physically construct these circuits to observe their behavior, and because the concepts of current and resistance cannot be physically observed, the statements would tend to be more theoretical than empirical. Admittedly, I had not considered the role of generalization for either discussion prior to this analysis.

The keyword maps for the graded discussions' content of interactions is shown in Figure 4.27.

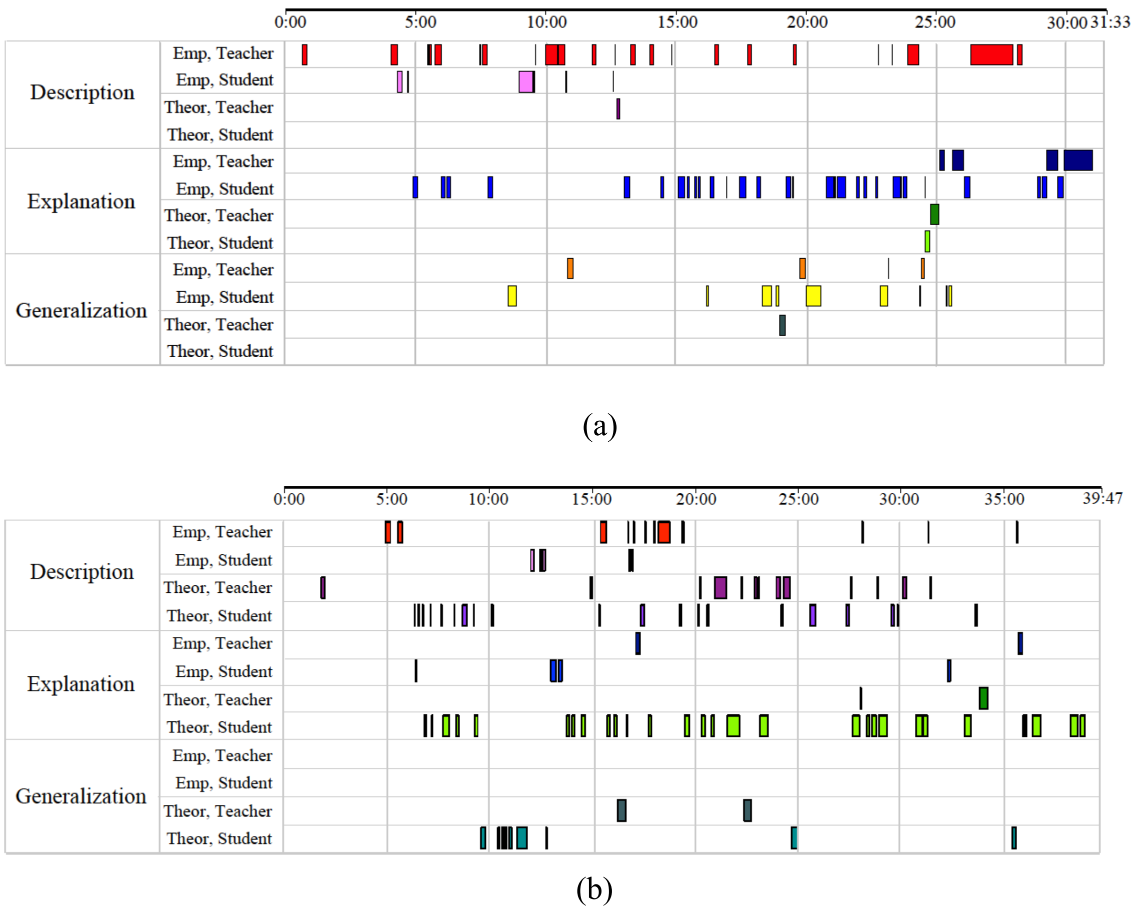


Figure 4.26. Content of interactions keyword maps for graded discussion 1 (a) and graded discussion 2 (b).

As I expected, the first discussion incorporated empirical contributions in the content of the interactions; students could make predictions based on the observed behavior of the cart. In fact, Shawn described the predicted position versus time graph when he said that "it would be going up in a positive slope and then it would kinda slant off at the top and go back down into negative slope" (GD 1, 0:04:19). Moreover, the students made explanations based on their observations, such as when Gregg challenged any shapes that were representing pauses at the top of the motion said "it never really stops - it just keeps going. Like it goes away from it then it comes back without ever stopping" (GD 1, 0:12:13). Empirical explanations were the dominant content of the interactions mapped in the first graded discussion, especially in the second half of the conversation when choices were being challenged and students wanted to justify their support of one graph over another. Interestingly, it took a long time before a student submitted the correct shape for the velocity versus time graph, but Tom eventually said, “I wanna say that it could be just a straight line and starting a little bit up on the velocity, and then go negative. ‘Cause some point the velocity has to be negative” (GD 1, 0:21:55).

The first graded discussion also included more generalizations than in any of the board meetings; for example, Lillian discussed the difference between decreasing velocity and a negative velocity by saying, “there's a difference because decreasing means that um, like it's um, going like the numbers are really going down, but negative doesn't necessarily mean that. It just means that like the slope is, ah the slope is negative” (GD 1, 0:19:59). Trevor introduced a generalization about what information is presented in a velocity versus time graph when he said, “velocity versus time graph isn't showing the position, it's only showing the velocity” (GD 1, 0:25:29). Overall, there was more variety of student content types in this discussion than in the previously analyzed discussions.

In the second graded discussion, the physics content lent itself more readily to theoretical descriptions, explanations, and generalizations. For instance, Jack proposed a portion of the circuit ranking by saying, “I think E would be the 3rd least resistant, because um the electricity has to go through the first bulb and then it splits” (GD 2, 0:09:11). He provided a description first, and then an explanation, but both components were theoretical in that they were not directly observable. In addition, students made generalizations about electrical circuit behavior, such as Bobby saying, “the more parallels that there are the less resistance there is” (GD 2, 0:09:33).

Although the physics content did tend to be more theoretical in the circuit rankings context, some students did make empirical contributions to the discussion. For instance, one student brought up her experience from lab activities earlier in the unit by saying, “when we like set up a parallel one in a single circuit weren't their brightnesses like the same?” (GD 2, 0:12:56), and this was an attempt to connect the predicted behavior of the ranking circuits with circuits they had physically constructed and then observed in the laboratory. Also, a student made an empirical contribution by making an analogy between the movement of students in the hallway and the behavior of electrical circuits; she stated, “Like the hallway like over there how some people keep going straight and some people go that way ‘cause there's less people. So if there's more paths, there's least resistance ‘cause more, there's more current” (GD 2, 0:24:41). Overall it seems good to know the tendencies for the content of interactions in the discussion, but the connection to the empirical seems helpful for some students.

Communicative Approach. Because my purpose for conducting the graded discussions was to hear as many student voices as possible, I expected that the presence of an interactive/dialogic communicative approach would dominate the keyword maps. The keyword maps for the graded discussions’ communicative approach are shown in Figure 5.7.

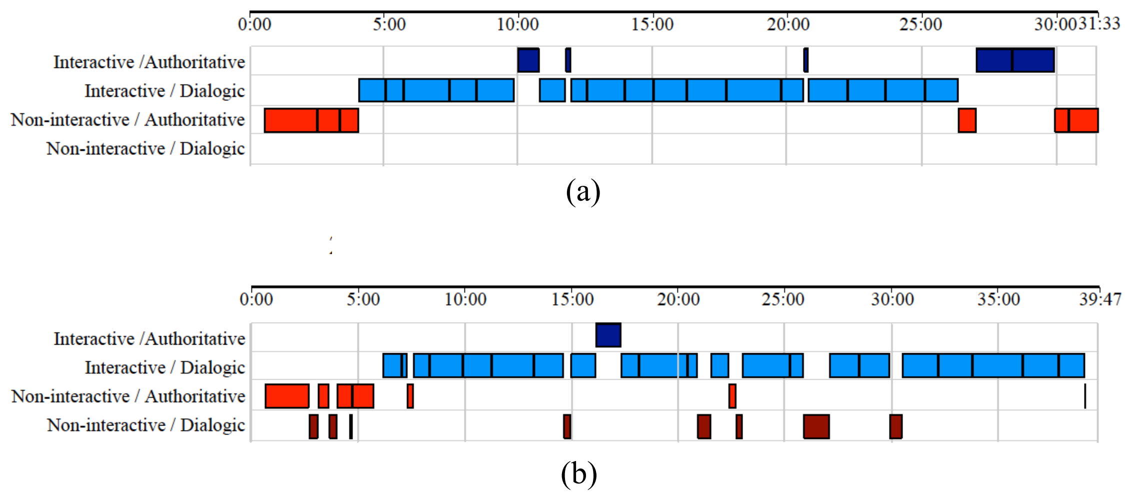


Figure 4.27. Communicative approach keyword maps for graded discussions 1 (a) and 2 (b).

As I had expected, the interactive/dialogic communicative approach did dominate both graded discussions; on the keyword maps, the bars for this approach are nearly solid throughout the length of the discussions.

In the first graded discussion, this exchange occurred when discussing the amount of time the cart spent at the top of the ramp before starting to travel downward:

Jason: *A half of a millisecond.*

SH: *A half of a millisecond?*

Jason: *Yeah.*

SH: *Have you timed this? 'cause that's, it's a very specific number.*

Jason: *Yeah I did actually I did it right before I came to school.*

SH: *Good for you, good for you, some people are sleeping, but you're up, taking data, measuring.... that's excellent. You know I wish I'd have known this sooner I would have adjusted your grade. Trevor what are you thinking? What were you gonna say?*

Trevor: *I was gonna say it does stop for just a slightest amount of time.*

SH: *Okay, um, all right. So ah Lorna what are you thinking?*

Lorna: *With the green one, at the very top of the, of the curve, at one point he slope is equal to zero which would indicate it is like stopping.*

SH: *So you're saying that this green one is consistent with the fact that it does stop, but it's only gonna be for a point instead of an interval of time. Okay, Alex, what do you think?*

(GD 1, 0:12:34)

The passage involved some humor as I commented on the student's joke about the length of time the cart was at the top of the ramp. Assuming that most adolescent students would rather be sleeping, I jokingly acknowledged that he did in fact wake up early to collect data. However, this interaction became a power issue when I made the comment that I would have adjusted his grade had I known about his behavior. The grade change I inferred would have been to increase Jason's grade because of his behavior, while many joking interactions between students and teachers about grades involve the lowering of grade. Nevertheless, there is certainly a power differential between Jason and me that was introduced with the mentioning of altering grades. Other ideas are heard, and although these ideas are shared with the class there is no indication of which ideas are consistent with the scientific view.

In the second graded discussion, student ideas were also explored:

SH: *Say that again*

Trevor: *Since um they're set up in parallel there is gonna be the same amount of current going through each bulb as in A. But since there's two loops, there's gonna be twice the current.*

SH: *What do people think about Trevor's answer? Sawyer you wanna comment on that?*

Sawyer: *Well I just wanna say yeah, that's that's a great point, 'cause in our experiments again we saw that in, what would be E by adding the parallel circuit in there the the top bulb was bright, because it had twice the current flowing through. Because it provided for both of the ah bulbs of the parallel circuit*

(GD 2, 0:13:58)

In this exchange, not only does Trevor propose an explanation for the current flowing through the circuit, that argument is supported by another student in the class, Sawyer.

A non-interactive/authoritative approach was also present at the beginning of each discussion to introduce norms and expectations. For example, when introducing the self tallying, "I'm gonna need your help with this because I can't remember how many times you've spoken if in case I miss something. So as a backup what I'm asking you to do is; hold your hand when you wanna contribute, and give me a sign to show how many times you've spoken" (GD 1, 0:02:50). Toward the end of the first discussion I said, "So, looking at time, we've only got five minutes left. I think what might be good for us is to run it. And then compare what we've observed in the data to this" (GD 1, 0:26:20). Similarly, in the introduction to the second graded discussion I said, "It's important to listen to one another. If somebody asks a question, we're gonna go ahead and make sure that question gets answered before we move on" (GD 2, 0:02:50). Such interactions are necessary to control the logistics of a discussion, whether it is to maintain equity of contributions (with the tallying) or maintaining student dignity (with acknowledging all questions introduced by students).

There were some portions of an interactive/authoritative communicative approach in the first graded discussion, with one appearing toward the middle and the other toward the end of the discussion; it is during this portion that the cart and ramp data were collected and the scientific story was introduced. Since the interactive/authoritative approach is associated with the development of the scientific story, and there was minimal introduction of the scientific view in the second graded discussion, there was only one segment of the interactive/authoritative approach:

SH:	*Does anybody remember how we kind of defined what a series of circuit is? Karri?*
Karri:	*Isn't a series when ah the current goes through the first bulb but also has to go to the second one too*
SH:	*So would you say that both of these are in series?*
Karri:	*Um, I would say no, I would say that the first, or the second one B has a series on the right side.*
SH:	*Okay.* (GD 2, 0:16:31)

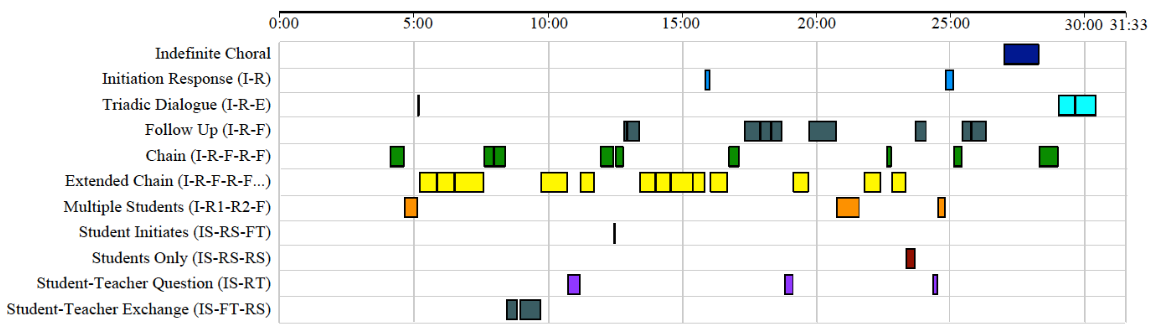
This segment addressed the definition of a series circuit, and it was interactive because I sought her input, but it was authoritative in that there was ultimately one correct view to define a series circuit.

When examining the non-interactive/dialogic communicative approach, the first graded discussion did not include any example; the second discussion included several instances of this approach. For example, when describing the expectations for the second discussion, I shared this story by saying, “after the last group conversation, a student approached me and said, ‘Mr. Hovan, I'm shy. Is there anything I can do, because I didn't contribute in the conversation?’ And my response was, ‘Yes. The next time, talk’” (GD 2, 0:03:41). Likewise, after polling the class to assess confidence in the current rankings, I remarked “most people actually said that they're pretty comfortable with this being here and this being here, when I did the poll, right? So that means these three are making up the biggest amount or uncertainty in this conversation right now" (GD 2, 0:26:13). This approach can allow student ideas to be revoiced by the teacher to the rest of the class, positioning them with increased academic status in the classroom (O'Connor & Michaels, 1993). I did reiterate some student ideas, such as, "Jason brought up A has a single bulb, B has a single bulb here, but in addition to the single bulb it has to go through another bulb. Dylan said, yeah but it's in parallel, so that's gonna make it less resistant" (GD 2, 0:20:57). However, in this graded discussion, my sharing of particular student ideas likely does not achieve the same status outcome that O'Connor and Michaels (1993) discuss; while these references to student ideas provided students authority to accept or reject my statements as appropriate interpretations of their remarks, without the validation that the student-generated idea resonates with and supports the scientific story, these discourse moves do not have the opportunity to elevate the status of the student speaker.

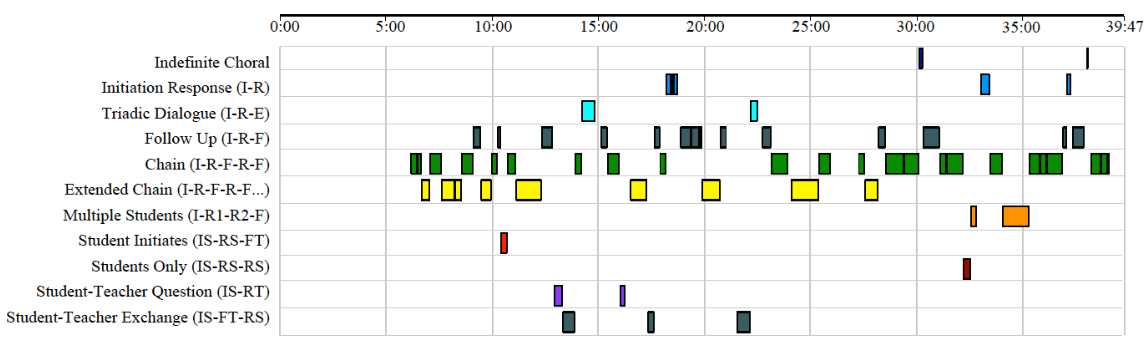
Overall, I feel like I did a disservice to the students in both graded discussions because of the overall lack of the authoritative approach needed to develop the scientific story. In the second discussion, we spent nearly 40 minutes talking about ideas but did not formally introduce the scientifically accepted view until the following day.

Patterns of Discourse. Although I had not considered the patterns of discourse prior to the graded discussions, my experience with this genre would help me predict what to expect. As the conversation facilitator, I typically would usually call on a student, and once they responded, I would ask a follow-up move to have the student elaborate. As a result, I would expect that the most frequent interaction pattern would be the *I-R-F-R-F* chain, a sequence of responses and follow-up moves to those responses. I had not formally considered the extent of student-initiated contributions or student-to-student interactions for these discussions.

The keyword maps for the graded discussions' patterns of discourse are shown in Figure 4.29. Both maps show that the discussions relied on three main types of discourse patterns, with each of those



(a)



(b)

Figure 4.28. Patterns of discourse keyword maps for graded discussions 1 (a) and 2 (b).

utilizing a follow-up (*F*) move rather than an evaluative response (*E*) by me. For example, this exchange occurred between me and a student when predicting graph shapes in the first discussion:

> *SH:* *So ah Lorna what are you thinking?*
>
> *Lorna:* *With the green one, at the very top of the, of the curve, at one point the slope is equal to zero which would indicate it is like stopping.*
>
> *SH:* *So you're saying that this green one is consistent with the fact that it does stop, but it's only gonna be for a point instead of an interval of time* (GD 1, 0:12:58)

In this exchange, I restated the student's response without evaluating it as correct or incorrect; it is an example of an *I-R-F* sequence, which was one of the most common patterns in the discussion. In addition, the first graded discussion had a prevalent presence of extended chain interactions:

> *Colin:* *I was wondering if um we could switch it so that it was more like a 'U'*
>
> *SH:* *Why do you think that?*
>
> *Colin:* *'Cause I mean normally we would start from the top of it, but instead we're starting from the bottom, which isn't, you know. So I see it as like since we're starting at the top and it's making that kind of um I don't know whatever you would call that, a "C" on its side.*
>
> *SH:* *Mm-Hmm.*
>
> *Colin:* *Um since we're starting on the other side, wouldn't it be flipped?*
>
> *SH:* *When you say starting from the other side, are you talking about other side of the track or the side of the graph?*
>
> *Colin:* *The other side of the track so.*

SH: *Okay, so we're starting from the bottom of the track, and you're proposing this slope.* (GD 1, 0:06:48)

This exchange continues because of the student's willingness to answer my clarification questions, and it results in a prolonged interaction pattern. The same three patterns of discourse were dominant in the second graded discussion, with a little more usage of the interaction chain than in the first graded discussion.

In both graded discussions, there were limited instances of student-initiated (*SI*) interactions, and there was only one example of student-only interactions in each discussion. One example of the student-only interactions in the first graded discussion occurred between two students challenging a graph with a plateau by discussing the length of time the cart is stopped at the top of the track:

Sawyer: *So because of that you don't really need really. It's almost like by having the plateau you're saying it's at zero for too long. And because of, 'cause it is it is at zero but it's not at a discernable amount of time. That's why it just has-* [nearly overlapped speech]

Gregg: *-Like the second it hits zero, it instantly starts to-*

Sawyer: *-Yeah, exactly.*

Gregg: *It doesn't stay at that spot.* (GD 1, 0:23:20)

This exchange demonstrates the level of interest that the two students had when presenting their argument; Gregg was so interested in supporting Sawyer that he interrupted Sawyer's statement to offer his support. Likewise, in the second graded discussion, one student, Lia, asks a clarifying question of Shawn in his proposed ranking arrangement:

Shawn: *‘Cause with E no matter what path you take you have to go through two. With A you only have to go through one, and then with B you have a choice between one or two.*

Lia: *Don't you have a choice with E too? You can through one or the other.*

SH: *Don't you have a choice with E too, she says Shawn?*

Shawn: *Yeah, you have a choice but no matter what choice it is you have to go through two because you have to go through the first one…*

Lia: *Oh, like the first bulb*

Shawn: *then go through the second one as well*

(GD 2, 32:14)

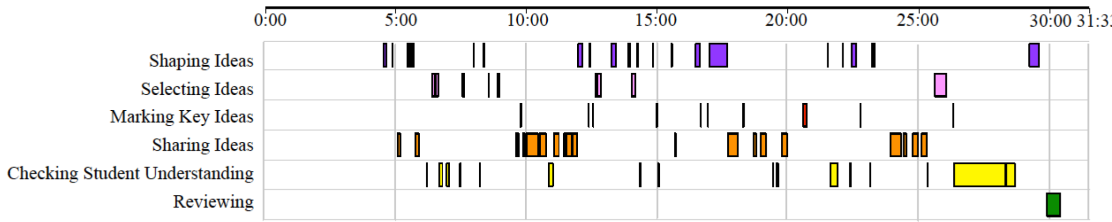
In this example, Lia took the initiative to ask her peer why he proposed his order of ranking the circuits. Shawn responded by explaining his thinking. I intervened by restating her question, but I directed it toward Shawn for his response. As with the other student initiated dialogue sample, both the participants were animated as they engaged highly with the ideas and they tried to make sense of what was being said; my involvement was just to make sure that the student question was addressed.

I was pleased that the dominant patterns of discourse in both graded discussions were chains and extended chains; these interaction patterns suggest that I am comfortable encouraging students to elaborate on their thinking as I facilitate the conversation. As the chains become longer, the discussion becomes more coherent and conversational rather than a blurting of disconnected statements. The minimal use of evaluative moves during these chains also minimizes the judgment students might feel (Wells & Arauz, 2006) and could possibly reduce their inhibitions to speak because the fear of being considered wrong is diminished. That being said, the evaluative portion of the triadic dialogue is often necessary during the introduction of the scientific story; the responses shared by students either will or will not be aligned with the scientifically accepted view of a phenomenon. In these discussions, then, the presence of triadic dialogue coincides with the development of the scientific story, and this is especially noticeable toward the end of the first discussion when the data from the cart travelling up and down the ramp is being discussed with the class. However, because the scientific story was never introduced in the second discussion ranking electric circuits, the presence of triadic dialogue is noticeably absent in the end of the second discussion; this is an example of the absence of the authoritative approach having a negative outcome.

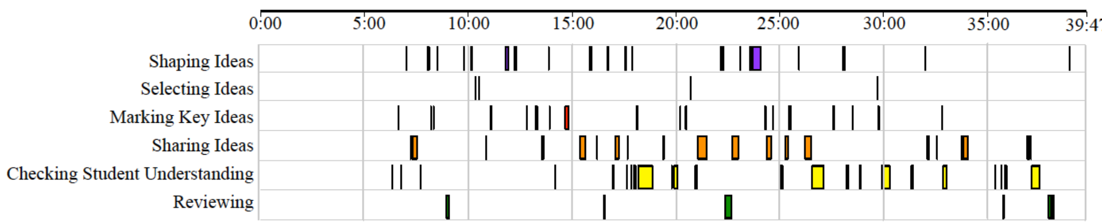
I did not anticipate nor did I really facilitate the discussion to encourage student-student responses. In addition, although I did offer student questions as one of the three common contributions to the discussion, I did not push for them or emphasize them during the discussions themselves. After examining the two samples of student-student exchanges and witnessing their level of animation, I am interested in restructuring group discussions to make these exchanges more commonplace.

Teacher Interventions. As I have already said, stating my intention for facilitating these graded discussions was mostly to share ideas that were presented by other students. Ultimately, then, we would share the results, interpret them together, and I would check for student understanding.

The keyword maps for the graded discussions' teacher interventions are shown in Figure 4.30.



(a)



(b)

Figure 4.29. Teacher intervention keyword maps for graded discussions 1 (a) and 2 (b).

Both of the discussions demonstrated the variety of teacher interventions that can be present in a class discussion. For instance, in the first graded discussion I shaped ideas when students described the graph and I responded with “Similar shape but a little plateau at the top?” (GD 1, 0:04:51), or when a student was trying to challenge the existence of a plateau, I responded with “So you're saying that this green one is consistent with the fact that it does stop, but it's only gonna be for a point instead of an interval of time” (GD 1, 0:13:15). In both of these examples I attempted to paraphrase a student’s response as a way to work on ideas. In addition, in the latter example I used the intervention to introduce the phrase ‘interval of time,’ which becomes important when studying average versus instantaneous velocities. I shaped ideas in the circuit ranking lesson when I paraphrased a student’s suggested move and said, “so the thing you feel pretty comfortable with and the thing you're proposing is that we move this to the end”

(GD 2, 0:08:02). Similarly, I affirmed student suggestions with comments like “So you think A might be before D - there's less resistance in A?” (GD 2, 0:23:04). Similarly, I shaped ideas through paraphrasing in this exchange:

SH:	*What makes this not a series circuit? Karri?*	
Karri:	*Because they're not directly connected to each other, there's a break*	
SH:	*Yeah there's that little junction there*	(GD 2, 0:16:57)

In addition to the paraphrasing here, I also introduced the term junction, which the students had already seen but was not in the original student response.

I demonstrated the intervention of selecting ideas when I focused attention on a particular student response; he wanted to shift the plot upward to account for the fact that it was a little away from the sensor when we collected data, so I asked “is there a particular shape that you would like to promote as being one that we move up?” (GD 1, 0:06:21). Similarly, when two students each named Trevor proposed contradictory responses to the behavior of the cart with respect to the origin, I said, “All right, we've heard from both [Trevors]. They have conflicting positions on the position represented in the velocity. So what do you think? Does this graph suggest that the cart reaches the origin?” (GD 1, 0:25:36). In the second graded discussion there were fewer examples of me selecting ideas, but there was the following exchange:

Jason:	*Um, why was A more than, more resistant than E, because they both go through single light bulb at first?*	
Teacher:	*Who can speak to that?*	(GD 2, 0:20:34)

This was a selection of ideas because I selected the student question as the focus of the conversation; I required the next person to speak to that question (unlike graded discussions early in my career in which student questions sometimes went unaddressed).

In the discussions, I also demonstrated the intervention of sharing ideas. In the first discussion, I shared ideas when I commented, “for the sake of this prediction graph, let's just focus on from the time I've released it to right before I catch it. Good clarification questions there” (GD 1, 0:11:46). Likewise, after hearing a student’s important idea about negative velocity, I shared it with the class by saying, “Can I summarize it by saying, if the velocity is going the other way it has to be negative at some point?” (GD 1, 0:17:45). Similarly, I shared Lorna’s idea by saying, “Lorna brought up - when she was talking about that with the green one - that the slope is zero just for one point, an instant in time of one clock reading as opposed to a time span or an interval of time” (GD 1, 0:24:07). The purpose of sharing ideas is to make sure that everyone has access to the points in the discussion as the scientific story is developed and made available to all.

I was checking for understanding when I asked students to eliminate possible graphs when I said, “is there anybody who can give an explanation as to why maybe one of these other ones isn't working?” (GD 1, 0:28:19). I also checked for understanding in the circuit discussion when I asked students “do people agree with her clarification statement that these two bulbs actually have different current travelling through them?” (GD 2, 0:17:58).

I was reviewing when I spent a portion of time reviewing how our first velocity graphs were constructed, and I said, “Remember when we first made velocity graphs we drew them from our motion map? Remember, we took our arrows and we made the velocity graph. So these are velocity arrows from motion map” (GD 1, 0:29:55). This review was a reminder about something that we had developed early in the unit, and by reminding students about this representational tool I intended for students to make more meaning from the graphs they had observed. There were minimal examples of reviewing in the second graded discussion, such as the series and parallel circuit distinction that has already been discussed.

It should be noted, however, that Mortimer and Scott (2003) describe the teacher interventions as moves teachers make to *develop the scientific story* and make it available to all students in the class. This happens to an extent in the first discussion, especially toward the end of the conversation in which there is time spent checking student understanding interpreting the generated graphs. However, it is important to recognize that the interventions in both graded discussions, and especially in the second graded discussion, are sharing ideas, checking student understanding, and reviewing the ideas *presented by students*. These interventions were not applicable to the development of the scientific story because the scientific story had not been introduced during those portions of the discussion. Admittedly, if the coding had been done only for those teacher interventions related to the creation and sharing of the scientific story, there would be scant markings on the keyword maps. This is not necessarily a limitation of the analytical framework, but rather the context to which I am attempting to apply it is not a good fit.

Nevertheless, this finding is consistent with the earlier remarks I have made about reconsidering the goal and facilitation of graded group discussions.

Another point worth discussing is that there was an instance of tension in the circuits graded discussion in which a student was trying to check his understanding; it involved a question asked by Moe:

Moe:	*I don't know I'm not sure how like why D would have more or less resistance than E?*
SH:	*Great question, so who can answer that? Why does D have less resistance than E?*
Jack:	*Because before the junction there's a light bulb at E, which electricity has to go through that light bulb and causing it to be more resistant. `Cause it's forced to go through a bulb whereas D it has a choice to go through one side of the other on the loop.*
SH:	*Okay, how do you feel about that answer? Does that answer it or you need a little bit more?*
Moe:	*Yeah, it makes sense.*

(GD 2, 0:19:12)

Reading the transcript from this exchange does not seem to present an issue; however, listening to the audio recording presents a different story. Moe did not understand the reason, and even when I heard the audio recording I remembered thinking that in that moment that Moe was still confused. Yet, I went on. I did not reteach the concept or try to reframe the issue in a manner he could understand, because I was hoping that the students would be able to do so. There is a tension, then, with how much responsibility should be placed on students in discussions to clarify student confusion.

Overall, this analysis has provided the opportunity for me to examine my facilitation of group discussions in the context of making meaning. I have been able to consider the extent to which students' ideas are promoted in the class, and I have been forced to reconcile the perceived impressions and the observed outcomes that a self-study can provide. In the next section, I continue to examine my discourse facilitation by identifying and analyzing some of the specific tensions I experienced while facilitating these large group conversations. In the final chapter I share conclusions, discuss implications, and provide some ideas for further research.

Chapter 5 : Conclusion, Implications, and Areas for Future Research

The purposes of this self-study were to examine how my facilitation of classroom discourse contributed to meaning making in my high school physics classroom and to examine the tensions I experienced in the facilitation of this discourse. In this chapter, I provide a summary of the findings. I then discuss some of the implications for teachers and teacher educators interested in facilitating classroom discourse. I conclude by identifying potential areas of future research.

Conclusion

This research explored how my facilitation of classroom discourse contributed to meaning-making in the high school Modeling Physics classroom. Through the use of Mortimer and Scott's (2003) analytical framework, three board meetings and two graded discussions were analyzed. The coding and mapping of the framework – teaching purposes, social language and the content of interactions, the communicative approach, the patterns of discourse, and the teacher interventions – helped to characterize the classroom talk in my attempt to explore student views, introduce the scientific story, and make this scientific view accessible to all students in the classroom. Each of the sections is discussed in turn.

Teaching purposes. The analysis revealed that the flow of teaching purposes in the group discussions and the scaffolding I provided were related to the opportunities for students to make meaning in the discussions. The board meetings began with an opening up of the problem and an introduction to the norms and expectations for participating in the conversations. Then there was a dialogic portion in which students' views were explored, and the extent of this portion of the lesson varied by board meeting; in the first meeting it was rather long and in the second meeting the exploration of student ideas was limited to the first half of the discussion. After exploring student views, I attempted to facilitate the introduction of the scientific story, and the analysis of the board meetings revealed the importance of scaffolding in this process. For example, for the first board meeting, I assumed that analytical skills from earlier lessons in which students analyzed graphs (their shape, correlation of the linear fit, evaluation of vertical intercepts and interpretations of slopes) would transfer to the board meeting, and as a result I provided minimal content scaffolding to guide that first group discussion. This assumption was incorrect, and while I had provided the social scaffolding (Williams & Baxter, 1996) for participating in the discussion, I provided insufficient content scaffolding, which prolonged the opening of the problem, delayed the introduction of the scientific story, and minimized the opportunity for the scientific story to be internalized. However, for the third board meeting, I provided both more specific scaffolding directing students toward scientific content to consider (Wood, Bruner & Ross, 1976) and also the opportunity for students to rehearse their ideas in small groups (Barnes, 1992); these moves resulted in more time introducing the scientific view and a meaningful portion of time to support the purpose of internalization of that scientific view.

The graded discussions also began with an opening up of the problem and an introduction to the norms and expectations for participating in the conversations. And like the board meetings, there was a dialogic portion in which students' views were explored. However, my exaggerated desire to hear contributions from as many students as possible minimized the time to introduce the scientific story in the first graded discussion and completely eliminated the scientific view's chance to be introduced in the second graded discussion. Consequently, the opportunity for supporting the internalization of the scientific story was absent from both graded discussions. In retrospect, this analysis revealed that my intention of wanting everybody to speak in a graded discussion was not the best intent in regards to student learning; just because students were talking does not mean that students were learning (Brandenburg, 2008). A more beneficial alternative would be to first reduce the time spent exploring student ideas, and then after introducing the scientific story increase the time spent supporting internalization. Constructing meaningful questions would provide space for students to contribute to the discussion as they work on ideas internalizing the scientific view.

The analysis of teaching purposes revealed how my facilitation of the discussions had a tremendous effect on the ability of students to make meaning during these discussions. All of these discussions had elements of the opportunity for learning described by Vygotsky (1978) and Mortimer and Scott (2003); they were social situations in which ideas were rehearsed between people through talk. However, in some of these group discussions, because I did not scaffold the conversation content or facilitate the discourse in such a way that introduced and supported the internalization of the scientific view, exactly *which* ideas the students reflected on and made individual sense of was not clear. The limited time spent introducing the scientific story and guiding students to support its internalization had as its byproduct the reduced opportunity for students to make meaning from the first two board meetings and both graded discussions. This analysis has resolved the tension I have experienced for years trying to determine the appropriate level of content scaffolding entering into these discussions; I now know the deliberate identification of graph shape, correlation of linear fit, evaluation of the vertical intercept, and the interpretation of the slope properly limited the degrees of freedom of the conversation (Wood, Bruner & Ross, 1976) and provided the opportunity for students to make meaning from these key attributes of the board meeting.

Social language. The aspect of social language is divided into the sections of teacher talk, student talk, and the label of social language.

Teacher talk. Examining the social language of the board meetings revealed much about the quantity and type of my talk in these group conversations. In the three board meetings my contributions amounted to around 75% of all conversation, and the majority of my speech used the scientific social language. For example, in the first board meeting I asked students, “what do those things mean if it doesn't start at the origin and it doesn't have the same sign slope?” (BdMtg 1, 0:16:18). Likewise, in the projectile motion board meeting, we discussed the change in velocity and I stated, “It's accelerating downward, and what kind of accelerations were people getting?” (BdMtg 3, 0:08:13). These statements are two of the numerous contributions that I made that employed the scientific social language. From the student perspective, while engaging in the scientific social language is one aspect of the Discourse (Gee, 2011) of being a successful science student, discussions in which the predominant social language is technical can limit the engagement of students in the class. When Lemke (1990) studied student engagement as a function of technical versus colloquial classroom language, he found that “in fully 89%

of these instances of more colloquial, more humanized ways of talking science, the engagement of the class with what was being said increased significantly (up to the high level of engagement for that class)" (p. 136). I am risking losing the engagement of some students if I am not cognizant of my propensity for using the scientific social language.

In the graded discussions, the presence of my talk was smaller (around 60% for each discussion), but still constituted the majority of the conversation. This majority was partly result of the discussion structure; as facilitator I served as the intermediary from one student contribution to the next, and a fair amount of my talk was procedural in nature as I called on various students to contribute to the discussion. In addition, as facilitator, my use of the everyday social language was higher than the scientific social language; my social language contribution comparison was 34% everyday to 29% scientific for the first graded discussion and 40% everyday to 16% scientific for the second graded discussion. Part of the reason for the smaller component of scientific social language for the second graded discussion was that the scientific story was never introduced, so I was not involved in the scientific social language associated with the scientific story. I had hoped that my high percentage of everyday social language was in part because I was expressing the relationships between concepts "in ordinary colloquial language as well as scientific language, insofar as possible" (Lemke, 1990, p. 173), but that was not the case; further analysis revealed that many of my contributions were more procedural contributions eliciting student elaboration, such as "Why do you say that?" (GD 2, 0:07:42) or "Can somebody speak to whether or not you agree or disagree with that" (GD 2, 0:08:34).

The propensity of teacher talk measured in this study conflicts with my perception that my classroom is student-centered; this is particularly challenging because I have experienced considerable professional development that incorporated discourse in the physics classroom. As a participant in the University of Washington's Summer Institute for Physics and Physics Science Teachers, I observed how the instructors modeled the interactions during conversations at key points in the *Physics by Inquiry* curriculum (McDermott & Shaffer, 1996); instructors did not directly answer my or any other teacher's questions directly, but rather the instructors provided another question to "help guide the teachers through the reasoning necessary to arrive at their own answer" (McDermott, 1990, p. 739). Similarly, I was a participant in a three-week Modeling Instruction workshop at Arizona State University. During this workshop the participants took on student roles to participate in our board meetings, and then after the board meetings we took on teacher roles to analyze the discourse moves demonstrated by our workshop facilitator. With these and other professional development experiences as my foundation, I developed a sense that I was trained to foster student-centered discourse. In addition, I received marks of "exemplary" for the questioning and discussion categories in my school district's observations of my own teaching, and the observation report even read, "Your exemplary use of questioning and discussion techniques engaged your students and required them to assume considerable responsibility for the success of the discussion" (Carlson, 2008, p.4). Nevertheless, this analysis showed that my voice dominated group discussions and I still defaulted to teacher-centered instructional moves. While I am not able to propose a specific target for teacher talk percentage, I would be interested in examining a board meeting in which I talked only a small portion of the time or if I were removed from the conversation altogether. Nevertheless, to deliberately decrease the amount of teacher talk below 75%, I will need to modify my instructional model for facilitating board meetings. This study suggests that even an experienced teacher with considerable training in promoting student discourse struggled to implement effective experiences for meaningful discourse.

Student Talk. The quality and type of student talk varied for the three board meetings, and examining both the periods of silence and the contributions that students made can characterize the student talk that was present in those conversations. In examining the amount of silence that was present when I was not talking, the first board meeting included four periods of silence that each lasted about 30 seconds or longer, and two additional periods of silence that lasted around 20 seconds in length; these periods of silence created tension in me as facilitator because I assumed students would contribute more readily. However, the periods of silence contrast with the third board meeting analyzed; in the third board meeting there were no periods of silence lasting more than 10 seconds, suggesting students knew the content to contribute to the conversation and were comfortable speaking. When students did speak, their contribution totals in the first and third board meetings analyzed were about the same (26% and 25% of all talk, respectively), and the percentage of student contributions in the scientific social language was also pretty consistent (20% in the first board meeting to 19% in the third board meeting). Lemke (1990) stated that just as with learning a foreign language, “fluency in science requires practice at speaking, not just listening” (p. 24); the amount of students’ use of the scientific social language in the board meetings suggests that students have had practice at speaking the language of science. Moreover, Mortimer and Scott (2003) state that learning science "involves being introduced to the language of the scientific community" (p. 13), so as students successfully engaged in the social language of science, students had the opportunity to learn science. It is important to note that as the amount of content scaffolding increased, the frequency and length of extended periods of silence decreased. While it is difficult to ascertain the extent to which facility with the scientific social language affected the amount of silence in the discussions, the level of comfort using the scientific social language likely contributed to the dynamic of group discussions and warrants future exploration.

In the graded discussions, although the class composition was slightly different from the first to the second graded discussion, the students showed growth in their use of the scientific social language from 26% to 35% of the classroom talk. Interestingly, the highest percentage of students participating in the scientific social language (35%) occurred when my usage of the *everyday* social language was its highest (40%). Following the concept by Arons (1997) of "an idea first and a name afterwards," (p. 345), it would be interesting to determine if an instructor using a higher percentage of everyday language to introduce a concept would result in students entering into the scientific social language more readily.

Social language. Although this section suggests some growth in students' use of the scientific social language, I would like to address a challenge I faced regarding the label of scientific or every day social language. In this analysis, the coding of social language was determined primarily by the vocabulary that students used in their talk; if the contribution incorporated scientific or technical vocabulary that was introduced in this physics class, I coded that contribution as the scientific social language. Similarly, if students correctly applied the technical or scientific vocabulary that they might have learned in other science or math classes or even in informal educational settings such as visiting museums or watching documentaries, I coded these contributions as the scientific social language. All other contributions were coded as the everyday social language. However, this application of social language based on the demonstrated vocabulary is limited in its ability to successfully assess student's scientific understanding. Specifically, consider this contribution that a student made to describe electrical resistance in the second graded discussion:

Ciera: *Like the hallway like over there how some people keep going straight and some people go that way 'cause there's less people. So if there's more paths, there's least resistance 'cause more, there's more current*

(GD 2, 24:41)

In the second half of the comment, the student used the words resistance and current, which according to my coding scheme would be coded as the scientific social language. If I were to only consider the first statement of the contribution, there are no scientific vocabulary words used, so I would code that statement as the everyday social language. However, in that first statement there is the communication of a scientific concept; the analogy comparing people walking through hallways with electricity in a circuit is able to demonstrate an understanding of how electrons behave in a circuit without using scientific vocabulary. Such a contribution demonstrating scientific concepts without using scientific vocabulary is not readily coded through the binary classification of the scientific or the every day social language as I have used it.

Interestingly, this student's facility to communicate a scientific concept without using scientific vocabulary could indicate two possible levels of understanding. For instance, a student using everyday language to describe the scientific concept could be an example of the student working with the ideas and trying to make sense of the scientific concept before being comfortable with the scientific language. However, the use of an analogy could also demonstrate the language faculty of a person who is completely comfortable with the scientific social language and is able to translate the scientific social language into the everyday social language to make the scientific concepts accessible to others. Overall, the binary analysis of the social language of the contributions in this study resulted in limitations that could be explored further through a more detailed interpretation of the scientific social language and a more diverse coding scheme.

Content of interactions. The content of interactions explored the descriptions, explanations, and generalizations in the discussions and whether those contributions were empirical or theoretical. I expected the dominant contributions to board meetings would be descriptions and explanations; introducing the first board meeting, I instructed students to "Look for similarities, and once we've exhausted all of those similarities, we move into how the whiteboards look different and we try to justify those differences" (BdMtg 1, 0:04:08). It would have been more clear to instruct students to *describe* the similarities between the graphs and then *explain* the differences between the graphs; this instruction would communicate the role of speaking in the Discourse of being a participant in a physics board meeting. The language I used of ‘look for,’ and ‘move into how the whiteboards look different,’ is vague and assumes that students know I want them to speak about such similarities and differences. Students could have interpreted my instructions as just noticing things on the whiteboards, and they would not have been incorrect; increasing my clarity of communication would facilitate students entering this Discourse.

After applying the analytical framework, I realized that the three board meetings were all intended to lead to generalizations – the models that formed the focus of each unit. However, without considering the language of a *generalization* explicitly beforehand I did not frame the conversation as effectively as I could have. For example, in the introduction to the first board meeting, I described the discussion’s purpose as “we're going to actually discover the main points that help us understand about position versus time” (BdMtg 1, 0:03:13). I never stated *why*; I never said that we were looking for a rule or model that would *generalize* the relationship between position and time for this type of motion. Later, once we had worked through the analysis, I began concluding the board meeting by saying, “now we can start making predictions about position versus time for this type of motion” (BdMtg 1, 0:28:23); unfortunately, this statement did not explicitly mention a generalization, or a model that provides predictive power for constant velocity motion.

With the graded discussions, contributions were affected by the physics context of the problem. Specifically, in the first graded discussion, the student contributions were mostly empirical because they were based on an observed cart and ramp phenomenon. If

I had considered this empirical nature of the content beforehand I would have been able to extend student thinking and consider ideas for possible theoretical questions. For instance, it might have been interesting to pose a theoretical question about how the students' perceived interval of time for zero velocity motion at the top of the ramp might change as the ramp angle were changed. In the second graded discussion, the content of the discussion was the unobservable property of a circuit's resistance. Although students were willing to contribute to the conversation, I think considering the content of these interactions might have added depth to the discussion. Specifically, if I had been explicit with students about the fact that the entire conversation was concerned with something we could not directly observe, it might have contributed to their understanding about the scientific practice of using theory to construct scientific models.

Communicative approach. The communicative approach was the aspect of the analytical framework that first interested me in analyzing my classroom discourse; I hoped the analysis would reveal a high level of dialogic presence, because I equated that presence with a student's opportunity for learning. In my understanding prior to this research, I assumed that providing a space for student talk was equivalent to the extraction of thoughts from students that Freire (1970) promoted; consequently, the extraction and mere vocalization of these thoughts would result in student learning. However, I now understand that the extraction of students thought, or the interactive/dialogic communicative approach does not guarantee learning; rather, it is the first step to meaning making in science. For example, in the passage below one student shares a prediction for the position versus time graph in the first graded discussion:

Melody: *Um, we had it so it kinda like plateaus at the top 'cause it like pauses for a second so it goes on a straight line and slants.*

SH: *Similar shape but a little plateau at the top?*

Melody: *Yeah*

(GD 1, 0:04:45)

This exchange was valuable because it provided the student an opportunity to propose a graph shape and support that claim with reasoning (the graph has a plateau *because* the cart pauses at the top). However, this contribution indicates a student misconception about the cart's behavior; the cart does not pause for an *interval* of time at the top of the ramp, but rather the velocity is zero for only an *instant* in time as the cart switches from travelling up the ramp to travelling down the ramp. One student attempted to address this idea later in the discussion:

SH: *So ah Lorna what are you thinking?*

Lorna: *With the green one, at the very top of the, of the curve, at one point the slope is equal to zero which would indicate it is like stopping.*

SH: *So you're saying that this green one is consistent with the fact that it does stop, but it's only gonna be for a point instead of an interval of time.*

(GD 1, 0:12:58)

Although this contribution is scientifically correct, I did not mark it in any way as being consistent with the scientific view. After running the cart and collecting data, I should have connected the data to this concept of stopping duration so students could make sense of the data that was collected in relationship to their understanding of the phenomenon. In other words, once the ideas have been shared, the authoritative dimension is necessary to guide the sense-making of those contributions that ultimately will lead to student learning. Consequently, as emphasized by Scott, Mortimer, and Aguiar (2006), both the dialogic and authoritative dimensions are necessary in science classrooms.

The communicative approach indicated much about the discussions in this study. In the board meetings, the non-interactive/authoritative approach was used to introduce the discussion, such as when I said, “I wanna give you guys just a couple of reminders about what we're looking at” (BdMtg 3, 0:00:45). Then student views were generally promoted with an interactive/dialogic approach, such as this exchange:

SH: *Who's willing to start the conversation?*

Briley: *The graphs all look the same.*

SH: *Can you talk more about what you're seeing?*

Briley: *Hmm, well, the velocity graphs looks pretty much like the same.*
(BdMtg 3, 0:03:20)

Using follow up moves such as asking students to talk more made these discussion portions dialogic in nature. In the second board meeting, the scientific view was introduced using a non-interactive/authoritative approach, such as when I said, “I want you guys to just follow along as we try to explore what this graph is telling us. Because it's telling us that the slope of your graph is related to one over the mass” (BdMtg 2, 0:19:06). In the third board meeting, I introduced the scientific view using an interactive/authoritative approach, such as in this interaction concerning air resistance:

SH: *If we wanted to really see you know air resistance, and you did a ping pong ball, how would your position and velocity graphs change for the horizontal?*

Tom: *The position graph would be curved.*

SH: *The position graph would have a curve.*
(BdMtg 3, 0:12:30)

In the second board meeting, I guided the development of Newton's Second Law in a format similar to a lecture. I was not successful at helping students connect their thinking to the scientific view because I did not provide the opportunity for the students to discuss and make sense of the content I presented; Mortimer and Scott (2003) suggest that if the learning demand is "high for a specific topic area, then the lessons need to be planned to allow plenty of time for teacher and students to talk through these new and unfamiliar ideas" (p. 108). I did not provide time for students to talk through the ideas I presented. Contrastingly, I did provide this time in the third board meeting when I gave student groups a few minutes to share their thoughts before the large group meeting. In the discussion, the scientific view was introduced through the interactive/authoritative communicative approach with more success in connecting student thinking to the scientific view.

In the graded discussions, because the expression of student views permeated the conversations, the interactive/dialogic communicative approach was dominant and any authoritative communicative approaches were minimal. As a consequence, students did not reach the level of scientific understanding that I desired; while they were able to work with and learn from ideas presented by their peers, there was minimal opportunity for the students to work through and make sense of ideas explicitly related to the scientific view.

In addition, both the board meetings and the graded discussions demonstrated minimal examples of the non-interactive/dialogic approach. The main examples present in the discussions were summary statements, such as "We've said that all the slopes are positive and that the number represents the speed" (BdMtg 1, 0:15:27). I did mention some students by name specifically, for example, when I restated a student's position and said, "Dylan said, 'yeah but it's in parallel, so that's gonna make it less resistant'" (GD 2, 0:20:57). However, in all five discussions analyzed, I only explicitly connected a student's contribution to the scientific view in one instance; during the projectile motion board meeting we discussed reasons for uncertainty in the video analysis and I said, "I think the first thing you said Karri, clicking on the points, is probably the reason" (BdMtg 3, 0:10:16). This was the only example of the discourse move of revoicing (O'Conner & Michaels, 1993) that I demonstrated, and overall, my limited use of the non-interactive/dialogic approach underutilized a strategy to explicitly consider various points of view (Mortimer & Scott, 2003).

Patterns of discourse. Analyzing the interaction patterns in the class discussions revealed much about my role facilitating discourse in the physics classroom. All five discussions revealed that I am comfortable using follow-up rather than evaluative discourse moves to encourage students to elaborate on their ideas; in many cases, this resulted in the formation of interaction chains with multiple turns for each participant. For example, when seeking predictions for the velocity versus time graph in the first graded discussion, this exchange occurred:

SH:	*What are you guys thinking for your predictions there? Let's try to get some people maybe haven't spoken yet Trevor.*
Trevor:	*I think it's gonna be like in the upside down V.*
SH:	*Upside down V so that shape?*
Trevor:	*Ah, no just a V yeah.*
SH:	*Okay, can you talk about why you think that?*

Trevor: *'Cause it's starting with the initial velocity and as it goes up the ramp it's gonna slow down. Then as it falls back down the ramp it's going to speed up.*

SH: *Okay, all right.*

(GD 1, 0:14:00)

My use of follow-up moves to confirm the described graph shape and to elicit elaboration of the student's thinking was successful at supporting a dialogic interaction (Mortimer & Scott, 2003). However, in the board meetings, there was still the presence of the discourse pattern called triadic dialogue, which tended to be convergent rather than divergent in nature but was useful for facilitating the introduction of the scientific story. For instance, in this exchange I asked about the graph's slope in the first board meeting:

SH: *So then what does the sign of the slope represent?*

Lorna: *It's going whether it's going forward or backwards.*

SH: *Which way the car is travelling, forwards or backwards.*

(BdMtg 1, 0:17:07)

The triadic dialogue (*I–R–E*) pattern was useful in this interaction because it resulted in a definitive interpretation of the sign of the slope of the object's position versus time graph, and in general the triadic dialogue was useful at arriving at the authoritative scientific view. In the graded discussions, because there was minimal introduction of the scientific story, the triadic dialogue discourse pattern was not as present.

It is worth noting that although the speech genres of board meetings and graded discussions are inherently different, the triadic dialogue has value in both speech genres as one means of introducing the scientific story. The purpose of board meetings is to *develop* a model, a generalization that describes a relationship between variables; the scientific view in this speech genre consists of the development of a model that (with simplifications) correctly represents the observed phenomenon. The function of the graded discussion is to *deploy* the existing model by applying it to an unfamiliar situation; the scientific view in this case is the correct application of the appropriate model to analyze the situation. Once student views are explored, the triadic dialogue can be used as a tool to connect the student's everyday view and the scientific view (Mortimer & Scott, 2003).

In all five discussions, there were minimal instances of student-student interactions or student-initiated interactions; however, consider again this exchange that occurred in the final graded discussion:

Lia: *Wait why did you say that we moved it there?*

Shawn: *'Cause with E no matter what path you take you have to go through two. With A you only have to go through one, and then with B you have a choice between one or two.*

Lia: *Don't you have a choice with E too? You can through one or the other.*

SH: *Don't you have a choice with E too, she says Shawn?*

Shawn: *Yeah, you have a choice but no matter what choice it is you have to go through two because you have to go through the first one…*

Lia: *Oh, like the first bulb*

Shawn: *then go through the second one as well*

(GD 2, 32:14)

During this exchange, the students were animated as they were seeking the answers to their questions; their peers were providing them with support to make meaning of the ideas (Rogoff, 1990). Lia was comfortable questioning Shawn in a manner more familiar than if she were to follow up with a teacher. Similarly, Shawn was comfortable responding to her question; she was a peer and not someone who was evaluating him. Overall, the positive dynamics of this interaction sequence revealed to me that I should be more deliberate in fostering student-student interactions in my classroom.

Teacher interventions. The analysis of teacher interventions revealed the complicated work of facilitating discourse. In this study's dialogic interactions, students first voiced their ideas. As facilitator, I shaped their ideas, sometimes by paraphrasing a student response or introducing a new term, such as when I said "it's only gonna be for a point instead of an *interval* of time" (GD 1, 0:13:15); this introduction to the word interval was done intentionally in context to apply it to the idea of a length of time. I selected ideas by focusing attention on a particular student's response, such as when I said, "Do people agree with Karri's interpretation?" (BdMtg 1, 0:23:43) or when I focused on one portion of a student's response, such as when I said, "You said video analysis, tell us more about that" (BdMtg 3, 0:08:55). I marked key ideas and also shared ideas by asking students to repeat their contributions, such as in the circuits graded discussion when I said, "I'm gonna ask you to repeat that 'cause you have a really good point" (GD 2, 0:13:14). The sharing of these ideas served as the means of providing access to the scientific story to all students in the class (Mortimer & Scott, 2003). It is important to note that this set of teacher interventions did not occur in a linear fashion in the classroom setting; the teacher intervention keyword maps in Chapter 4 represented the interventions as a scattering of different actions that I took in the facilitation of this discourse. The application of the Mortimer and Scott (2003) analytical framework provided a backdrop against which my interventions could be categorized; facilitating classroom discourse in the future I know now that with each discourse move, I could work toward the development and sharing of the scientific story.

After the scientific story was developed, the teacher intervention of checking student understanding was intended to "check the consensus in the class about certain ideas" (Mortimer & Scott, 2003, p.45). For example, when discussing the location of the origin in the first graded discussion, I asked, "when we don't manipulate any settings, just opening Logger Pro, the origin is the sensor - do you agree with that?" (GD 1, 0:10:50). However, I did not provide a structured space for students to respond to this question; some students nodded, but I do not know how many agreed. This unstructured approach to checking the consensus of the class occurred regularly; in the first board meeting alone I asked 'Do people agree with that?' seven different times, without ever providing a concrete opportunity to assess how many people *did* agree or not. If I had taken a poll or asked students to show their agreement using a 'thumbs up–thumbs down–thumbs to the side' formative assessment technique, I could have been more adequately informed about what the students in my class actually thought and how to move the instruction forward. Finally, the teacher intervention of reviewing provided the opportunity to return to and go over ideas, such as when I said, "Let's try to summarize what I think I've heard you say" (BdMtg 1, 0:26:52) to begin to recap the main points of the conversation. However, the presence of the reviewing intervention was limited to two of the three board meetings and was not present in the graded discussions.

Another finding from this research suggests that it might not always be appropriate to intervene, at least not right away. In the first board meeting, after an extended period of silence (36 seconds), one student tried to break the silence by making a contribution about a difference he noticed on the whiteboards. However, because of my intent on discussing the similarities first and the differences second, I responded immediately to the student - not by addressing his inquiry but by asking if his contribution was a similarity or difference. Upon hearing the audio recording of the interaction, my immediate response came across as a condemnation of his effort. In addition, my stern response was a likely reason that another long period of silence immediately followed this exchange; it was not reasonable to expect students to risk entering into such a discourse environment for fear of experiencing similar responses from me. While teachers have been taught to demonstrate ‘wait time’ after asking theie students questions, I suggest that teachers should also demonstrate ‘wait time’ before *responding* to student contributions as well; such a pause might provide space for more thoughtful and carefully crafted responses that promote discussion rather than hinder it.

Implications for Practice

The findings presented here have implications for teachers and teacher educators interested in facilitating large group discussions in their own classes. Some of the implications are as follows, and they are presented in roughly the same order that an instructor would use in the planning and delivery of the discourse lesson:

Determine the reason for the discussion. Prior to conducting the discussion, consider its intended purpose. The goal may be to find out what students already know, to explore ideas that students may have, or to introduce, develop, and internalize the scientific story. In this study, the purpose of the board meetings was to establish the models that identified the relationships between the variables being studied; in the analytical framework used in this study, this corresponds to the introduction of the scientific story and guiding the support of the internalization of that story. Believing that learning occurs in the internalization of the story as the ideas move from the social to the individual plane (Vygotsky, 1978), the teacher can be mindful that it is not enough to simply identify the relationship between variables, but it is necessary to provide time in the discussion for the students to work with the ideas to help make meaning from them. Similarly, the purpose of the graded discussions should have been to deploy the model in a new situation; this corresponds to the teaching purposes of getting students to work with scientific meanings and applying the scientific view. In the two graded discussions in this study, the purposes did not progress enough toward the application of the scientific ideas because too much time was spent exploring student views. Overall, being cognizant of the discussion's purpose can encourage a more deliberate facilitation of that discussion, especially assisting in being intentional about the allocation of time needed to accomplish the discussion's goal.

Moreover, there is a distinction between *introducing* the scientific story to the students and supporting students to *internalize* the scientific story. The mere mentioning of a scientific concept or the act of simply presenting the definition of a scientific term is not the equivalent of teaching it and will likely not result in student learning. This data reinforces the Vygotskyian perspective that introducing a scientific idea is the first step, but only after students have had the opportunity to work through and make sense of the idea will learning occur.

Provide the appropriate scaffolding for the discussion content. Align the scaffolding with the purpose of the discussion. If the intent of the discussion is to introduce and begin to internalize the scientific story, provide enough assistance and direction so that students have something to contribute to the conversation. In this study, I expected that student understandings from previous lessons on graphical analysis would transfer to the first board meeting. It did not, and one student even demonstrated the frustration described by Wood, Bruner, and Ross (1976) when he remarked, “We don't have anything to say” (BdMtg 1, 0:09:47). I realized that I had been more focused on the social scaffolding (Williams & Baxter, 1996) than the content scaffolding, so in the third board meeting, I provided explicit content scaffolding by asking students to consider each graph’s shape, correlation, intercept, and slope. This scaffolding seemed successful in that it changed the student focus during the discussions; namely, the scaffolding changed the student focus from ‘*What do I say?’* in the first board meeting to ‘*What does it mean?’* in the third board meeting. In our first board meeting, student attention was directed inward as they struggled with knowing what to say, and one student even claimed prematurely that they did not have anything else to say. However, in the third board meeting the student focus was directed outward to the whiteboards of other groups as they tried to make sense of what the different aspects of the graphs indicated or represented. This scaffolding focused the conversation (Wood, Bruner & Ross, 1976) on graph attributes that were known to all, thereby making the conversation more accessible to all students.

Consider the discussion's cognitive load. If the discussion involves introducing the scientific story, determine a reasonable amount of content to be included. Use questions to support the internalization of the scientific story, but be attentive to the dynamics of the group when considering the number of extension questions and or even their inclusion in the discussion. For example, in the projectile motion board meeting, my learning targets for the conversation were for students to recognize that constant velocity in the horizontal direction and accelerated motion in the vertical direction can be used simultaneously to model projectile motion. In addition, I expected that students could provide force analyses in both the horizontal and vertical directions to substantiate why the model works. My students met those learning targets, and I should have worked to provide students more opportunity to make meaning of the analysis as soon as they reached those learning targets. However, I went too far and asked a question about how students could obtain the initial velocity of the projectile from only using the graphs on the whiteboards. I felt that this was too much during the conversation, and although I failed to do so, I should have stopped and saved the question for a later time after students had more time to make sense of the original learning targets.

Provide an opportunity for exploratory talk. Students should be given the opportunity to discuss their ideas in small groups before entering a large group discussion. Just before the projectile motion board meeting, I asked the students to share their ideas about the specific science content that we were going to discuss. By providing the time for the students to engage in this exploratory talk (Barnes, 1992), the rough draft equivalent of speech, students had the chance to rehearse their ideas in a smaller, less threatening environment. Their ideas had already been tested and honed in the small group, and they seemed more willing to risk voicing their ideas in the large group discussion. In this board meeting, analysis revealed no periods of silence longer than ten seconds, at no point did students no students claim that there was nothing left to say, and the learning targets for the discussion were met.

Recognize the value in the use of everyday language. As Lemke (1990) has described, science has a mystique of being challenging because it includes such an extensive lexicon. The use of everyday language first to establish concepts can provide access for today's more diverse classrooms entering into the Discourse of science. For example, saying the 'speed of an object going in a certain direction' can describe the object's velocity, or the 'obstacles to the movement of charge' could describe the electrical resistance of a circuit. After students have demonstrated the ideas represented in these everyday definitions, the scientific social language could be introduced and practiced (Arons, 1997).

Acknowledge the necessity of both the dialogic and authoritative approaches. Originally, I equated the presence of dialogic discourse as an indicator of active learning, but this understanding of dialogic discourse is incomplete. As I have discussed, the analytical framework used in this study (Mortimer & Scott, 2003) identified four classes of communicative approach that contribute to meaning making in the science classroom. In addition, Scott, Mortimer, and Aguiar (2006) state that tension exists between the dialogic and authoritative dimensions, but both are necessary. Specifically, dialogic exchanges “are followed by authoritative interventions (to develop the canonical scientific view), and the authoritative introduction of new ideas is followed by the opportunity for dialogic application and exploration of those ideas” (p. 605). The ideas that students contribute in the dialogic portions of a lesson must be connected to and referenced to the authoritative portions in the development of the scientific story, because it is these connections that assist in meaning making for the students as they work toward developing their use of the scientific social language.

Align interaction patterns to teaching purpose. Construct divergent questions to elicit student ideas, and utilize follow-up (rather than evaluative) moves to encourage the elaboration of student thinking and provide a space for the practicing of scientific talk. However, when intending to introduce the scientific story, convergent questioning structures such as the triadic dialogue may be necessary to lead to the scientifically accepted view.

Check for student understanding. To monitor the degree of internalization of the scientific story, incorporate formative assessment strategies into the discussion. In this study, I asked ‘Do people agree with that?’ multiple times in one discussion in a questioning manner that was nearly rhetorical. By using formative assessment techniques such as taking a poll, using student response systems (‘clickers’), or asking students to show their agreement using a ‘thumbs up–thumbs down–thumbs to the side’ strategy, the instructor can be more informed about what the students think and how to move the discussion forward. Moreover, by requiring a response from each student when using these formative assessment strategies, the instructor can also monitor the level of student engagement at those points in the discussion.

Use revoicing. The use of the non-interactive/dialogic approach can serve as a way to recap the ideas of the lesson (Mortimer & Scott, 2003). In this study, the non-interactive/dialogic communicative approach was used generally to summarize ideas proposed by students in the discussion. However, when associated with student contributions consistent with scientific view, using the student's name in the discursive move of revoicing (O'Conner & Michaels, 1993) can promote the student's status in the classroom.

Consider the role of the instructor. Recognize that if the discussion will involve the use of the instructor as facilitator, the percentage of student talk time will be decreased. Prior to conducting this research I thought the amount of student talk in my classroom was considerably higher that what the analysis indicated. If the intent is to promote student-student exchanges and student initiated questions (which occurred minimally in this research), then it might be necessary to model such interactions, provide the necessary support for them to occur, and rethink the role of the instructor during the discussion.

Practice, practice, practice. Engaging in discourse is necessary to yield progress in participating in the Discourse of physics. Teachers will not become more comfortable facilitating discourse and students will not become more comfortable engaging in scientific discourse if the dominant mode of classroom instruction is lecture; students need the opportunity to rehearse ideas and make sense of ideas with one another. As

Lemke (1990) stated, the "one single change in science teaching that should do more than any other to improve students' ability to use the language of science is to give them more practice actually using it" (p. 168).

Areas for Further Research

The findings and implications of this research lead to some questions to be answered in further investigations. They are as follows:

In this study, there were different amounts of time spent on the exploration of student views, which resulted in varying amounts of time spent introducing the scientific story. One future study might explore the ratios of discussion time spent exploring student views to the time spent introducing the scientific story and supporting the internalization of that scientific story. While some topics in science have a higher learning demand and might need more time to introduce the scientific story and assist students in the internalization of that story, it would be good to look at classes in which students have been successful at internalizing the scientific story to look at trends in the ratios of teaching purposes that were demonstrated. In the projectile motion board meeting, about one-third of the discussion involved the exploration of student ideas with the remainder of time focusing on introducing the scientific story and supporting the internalization of that story. Providing the opportunity for exploratory talk might serve as a means of pre-selecting those ideas that are less pertinent to the discussion and might move the discussion toward the scientific story sooner.

The research presented here supports the claim that both dialogic and authoritative approaches are necessary in the classroom to assist students in meaning making (Mortimer & Scott, 2003; Scott, Mortimer & Aguiar, 2006). As I stated, Scott, Mortimer and Aguiar (2006) proposed that dialogic exchanges are followed by authoritative interventions, which then lead to the dialogic application and exploration of those ideas. The research presented here suggests that board meetings seem to emphasize the first two portions of that sequence (the dialogic and authoritative), but not much of the second dialogic exchanges. It would be good to explore whether a balance or proportion of dialogic and authoritative approaches exists that would best helps students learn.

In this study, the third board meeting utilized the strategy of small group exploratory talk (Barnes, 1992) prior to the large group discussion, and this discussion resulted in fewer pauses and an overall shorter meeting to discuss the pertinent content; there were no periods of silence longer than ten seconds, and at no point did a student claim that there was nothing left to say. The data suggest that the opportunity to discuss the concepts in the small group provided a rehearsal space for the large group discussion, but because of the timing of this discussion (nearly half way through the year), however, it is difficult to ascertain the extent to which the more succinct board meeting was the result of that small group exploratory talk time or how much was a result of the students having been together for so long. It would be interesting to try this exploratory talk strategy early in the school year and compare it to a class that does not incorporate this strategy to better determine the effects of this exploratory talk.

These findings analyzed a facilitation model in which the teacher served as the node of interactions; most conversational threads relied on feedback or evaluation from the teacher. This facilitation model resulted in the teacher contributing a minimum of around 60% of all talk with few examples of student-student exchanges or student-initiated interactions. A future study could explore if there is an ideal percentage of student or teacher talk in the classroom. Moreover, a future study could compare the teacher moves in facilitating this teacher-centered discourse with a discourse model in which student-student interactions and student-initiated contributions were the norm and then also comparing the development of the scientific story in the two settings.

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