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INQUIRY IN CONVERSATION:
EXPLORING THE MULTIPLE SOLUTION PATHWAY (MSP) LESSON STRUCTURE
AS A MEANS TO PROGRESSIVE DISCOURSE IN THE SCIENCE CLASSROOM

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by

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Abstract

This exploratory, descriptive study examined the way five chemistry teachers from four different schools enacted their visions of an activity labeled as the multiple solution pathway (MSP) lesson structure – one in which students were given a relevant problem to solve and the opportunity to propose and explore several solutions to the problem. A theoretical and analytical framework for characterizing what transpired within these enactments was developed mainly out of Bereiter’s principle of progressive discourse and its accompanying commitments, but also by drawing on Peirce’s fallibilist epistemology, Gal’perin’s notion of the orienting basis of an action, and Davydov’s distinction between empirical and theoretical generalizations. Data from utterance-level discourse analysis of the videotaped lessons, supplemented by pre- and post-lesson interviews with both students and teachers was used to answer the research question: What is the nature of the interactions that occur during Multiple Solution Pathway (MSP) lessons and how are those interactions related to the structure of activity and the way in which ideas are explored within those lessons? The data showed that there were two general structures of activity utilized by the five teachers and that these different structures impacted the extent to which two of the progressive discourse commitments (expansion and openness) were supported. It also indicated that the teachers likely operated off a ‘teacher as evaluator’ metaphor and a discrepant event vision of the way the lesson should unfold, both features of which limited the extent to which progressive discourse was maintained in these lessons. Pedagogical implications for more fully realizing the potential of the MSP structure are presented.
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Findings

Assertion 1

The two idea exploration structures differed in the opportunities they afforded for interactions related to the expansion and openness commitments, putting these two in opposition.

The CIES and EIES patterns differed in terms of the implicit view of trial-and-error they conveyed to the students.

The way the patterns supported/inhibited the expansion and openness commitment was mirrored by certain discourse moves employed by the teachers.

The CIES and EIES patterns and associated interactions produced variations in the way the normative scientific explanation was connected to both tenable and untenable solutions.

Assertion 2

The way teachers oriented students to key cognitive tools produced interactions which supported idea exploration in some case and constrained it in others.

Teachers’ nuclear initiating moves defined how ‘dead end’ instances were treated and how alternative ideas were explored.

The interactions related to discourse moves supporting the openness commitment were focused more on students’ ideas rather than on their reasoning.

Teachers participation in interactions related to the empirical testability commitment defined the students’ ownership of the process of analyzing the test results.

Implications

Adopting the proper metaphor and vision for conducting a lesson of this nature.

Providing the proper orienting basis for the activity.

Employing a structure of activity which effectively balances the expansion and openness commitments and promotes a sophisticated view of trial-and-error.

Utilizing a discourse model which fully taps the potential of progressive discourse and its associated commitments.

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Being in this moment is the result of a pursuit that has spanned my entire adult life. I have always been – for better or worse – single-minded in my quest to accomplish certain goals and none has driven me more than this one. Now that I have attained it, there is a genuine sense of the surreal – of a feeling I cannot fully put into words, no matter how much of a wordsmith I might fancy myself.

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Introduction

On the opening page of her often-cited article, Lampert (1990) discusses the way Lakatos portrays the generation of mathematical knowledge in *Proofs and Refutations*:

Lakatos’s argument . . . is that mathematics develops as a process of “conscious guessing” about relationships among quantities and shapes, with proof following a “zig-zag” path starting from conjectures and moving to the examination of premises through the use of counterexamples or “refutations.” (p. 30)

Later, in the same article, she compares that to the way mathematical knowledge is typically conveyed in schools:

In the classroom, the teacher and the textbook are the authorities, and mathematics is not a subject to be created or explored. In school, the truth is given in the teacher’s explanations and the answer book; there is no zig-zag between conjectures and arguments for their validity, and one could hardly imagine hearing the words *maybe* or *perhaps* in a lesson. (p. 32)

This same criticism concerning the disconnect between what occurs in the discipline and what takes place in the classroom has been levied by those in the field of science education (e.g. Lemke, 1990; Mortimer & Scott, 2003). The fact that typical discourse in science (and math) classrooms does not represent the kind of ‘zig-zag’ of which Lakatos and Lampert were speaking is not surprising given the stereotypical view of ‘teacher as authority figure’ to which Lampert alluded in the previous passage. It is also not surprising given the complexity of the interactions the teacher must orchestrate in such discourse – a complexity made clear in the following passage from O’Connor and Michaels (1996):

Consider a first-order description of the task . . . The teacher must give each child an opportunity to work through the problem under discussion . . . while simultaneously encouraging each of them to listen to and attend to the solution paths of the others, building on each other’s thinking. Yet she must also actively take a role in making certain that the class gets to the necessary goal: perhaps a particular solution or a certain formulation that will lead to the next step. (p. 65)

In the subsequent paragraph, O’Connor and Michaels summarize the nature of this
problem and indicate its pervasiveness: “The complexity of this task probably explains the relative rarity of productive classroom discussion as a site for intellectual socialization in elementary school; it is rare even in many secondary and college settings” (p. 66)

These four passages effectively set the stage for introducing the research that will be discussed in this dissertation because that research is focused on examining the kinds of interactions that occurred in a lesson structure (to be identified shortly) which has the potential for engaging students in the kind of ‘productive classroom discussions’ to which O’Connor and Michaels were referring. The objectives of this chapter are (1) to identify and describe that lesson structure, (2) delineate the research question and goals surrounding the investigation of that research question, and (3) present the theoretical framework that was developed in order to answer that research question and help achieve those goals.

*The Genesis and Nature of the Lesson Structure*

Liberating dark data takes this ethos one step further. It also makes many scientists deeply uncomfortable, because it calls for them to reveal their “failures.” But in this data-intensive age, those apparent *dead ends* could be more important than the breakthroughs.

--Thomas Goetz, *Freeing the Dark Data of Failed Scientific Experiments* (Goetz, 2007, italics added)

This study originated in a concern that this researcher had for what Herrenkohl et al. (1999) identified as the “mistake stigma, a myth that runs deeply through the fabric of school life” (p. 455). In response to this concern, while still a practicing high school chemistry teacher, the researcher developed a particular lesson in which students were, in fact, *likely* to make mistakes and were encouraged to struggle with those mistakes in order to come to a deeper understanding of a key chemistry concept.

Because of the connection between that lesson and the data collected for this research, it will prove useful to provide some details about it. The lesson begins by creating this scenario for
the students: There are two chemicals (zinc and sulfur) that when mixed together in the proper amounts can produce a reaction so exothermic that this mixture is often used in model rocket engines. One of the chemicals (usually the zinc) has been weighed out prior to the lesson by the instructor; the objective of the class for the lesson is to determine the amount of the other chemical (usually the sulfur) that must be weighed out. From there the students are charged with directing the action of the lesson by proposing ideas regarding the amount of the sulfur that should be used and providing rationale for their proposals. Proposals that are deemed by the class to be reasonable are tested for their efficacy (either immediately following their proposal or after other solutions have been offered) by weighing the suggested amount, mixing it with a pre-weighed sample of zinc, and igniting (or trying to ignite) the resulting mixture.

During this activity, the role of the teacher is to guide the discourse around the exploration of the various solutions proposed by students and, in the end, formalize the idea that produces the most efficacious result. The key feature of this activity is that – more often than not – the initial ideas proposed lead to the preparation of mixtures that do not burn adequately enough to power a model rocket engine. In other words, these initial ideas often result in the kind of failed attempts or dead ends that Goetz was discussing in his passage. Students must then work their way out of these wrong turns by trying to determine the mistake in the logic that lead to the unsuccessful proposal and how that might inform the production of a more successful proposal.

Thus, the lesson structure was originally labeled the Dead End to emphasize the importance of these ineffectual solutions and how they can be viewed as valuable resources for developing conceptual understanding. However, it was eventually recognized that this label focused all of the attention on just one portion of a larger lesson structure – a lesson structure in which a couple or several different ideas were offered and explored in response to a problem
posed. This larger lesson structure was dubbed the *Multiple Solution Pathway* (MSP).

The description of the ‘Zn-S Reaction’ lesson allows one to abstract out essential features of the MSP lesson structure as it was envisioned by the researcher prior to the beginning of this study. First, it involves presenting students with a realistic problem – realistic in that it represents a legitimate problem within the context of the discipline or the context of a potential application of a concept and realistic in that students genuinely have the background and skills needed to tackle it (although, ideally, it would push them to the edge of their zone of proximal development, Vygotsky, 1978, 1986). Second, it requires a willingness (on the part of the teacher) to allow students to make mistakes and to provide the necessary support (intellectual, social, and psychological) to help students learn from those mistakes. Third, it entails giving as much (or more) attention to the process of solving a scientific problem as it does to understanding the content at the heart of that solution.

*The Research Question*

The research program of which this study is a part has a long-term goal of trying to identify the fundamental elements of an MSP enactment which will allow it to most effectively generate the kind of ‘zig-zag’ of classroom discourse described by Lampert and to properly support the use of mistakes in the problem-solving process as a vehicle for learning. Once those elements have been ascertained, teachers could be shown how to integrate them into their practices (through professional development experiences). At that point, the research program could be directed towards examining the way in which MSP enactments structured around those fundamental elements impact the conceptual understanding of students participating in them.

However, it was recognized that none of what was described in the preceding paragraph could be accomplished without constructing the proper foundation on which to build the long-
term research program. The researcher recognized that the form that foundation would need to take was a characterization of the MSP lesson structure grounded in the enactments of practicing science teachers facing the constraints of the educational system in the 21st century. As such, a pilot study was undertaken in 2006 – 2007 in which the researcher examined the enactment of an MSP lesson in the classrooms of three other teachers (two biology and one chemistry) in the same school in which he taught, along with his own instantiation of this lesson structure. This dissertation study was an expansion of that undertaking into other teachers’ classrooms and other schools during the 2007 – 2008 school year.

Based on the description above, it should be clear that the purpose of this study was to examine the way the MSP lesson structure unfolded within the enactments of several different classroom teachers, with a goal of characterizing the key elements which determined the way that it unfolded. The research question that captures that purpose is, *What is the nature of the interactions that occur during Multiple Solution Pathway (MSP) lessons and how are those interactions related to the structure of activity and the way in which ideas are explored within those lessons?*

Given that research question, one of the key terms which must be understood within the context of this study is *interaction*. Unfortunately, a search through over a hundred articles published in the last five years and focused on studies of interactions in classrooms yielded not one explicit definition of this term. Moreover, in only a few of those articles was the discussion surrounding this term adequate enough to infer what the authors meant by it. One example of this kind of discussion is from a piece by Dennen and Weiland (2007): “The exchange of messages alone is not an indicator of interaction; at a minimum, linguistic indicators of intertwined action–reaction sequences are needed” (p. 283). This suggests that interactions
involve two or more *actors* or *subjects* who have experienced at least an instance of intersection in their ongoing activity. A second example is this passage from Moura (2006): “Human interactions are multimodal in nature. From simple to complex forms of transferal of information, human beings draw on a multiplicity of communicative modes, such as intonation and gaze, to make sense of everyday experiences” (p. 270). These words indicate that an interaction involves an attempt – whether successful or unsuccessful – on the part of the actors or subjects to exchange information or communicate through various modalities.

Based on a fusion of the features culled from the two sources above, the definition of interaction that will be utilized in this study is *the intersection of the activity of subjects which results in an attempt to exchange information or communicate*. There are three aspects of that definition that need to be addressed. The first is that it was written to indicate that an interaction must have a *minimum* of two or more subjects, but to include the possibility that there can be *more than* two participants (likely the case in a classroom context). The second is that the choice of the word ‘subjects’ rather than ‘actors’ is intended to convey the influence of *Activity Theory* (Leont’ev, 1977, 1978, 1981) on this researcher’s theoretical and analytical perspective. The final point is that the phrase ‘exchange information’ is meant to convey a concern for a broad range of communicative actions that includes both verbal and non-verbal processes (although the analysis of data in this research will emphasize the former).

One other issue related to the research question needs to be addressed at this point. While the content of that question indicates that the collection, analysis, and discussion of data needs to be focused on that data related to the exploration of ideas in the lessons being examined, it will not be possible to fully understand that data nor to determine its implications without a description of the larger context from which it emerged. That being the case, it will be necessary
to consider not just data directly relevant to the research question itself, but also supplementary information associated with such things as (1) the nature of the activity employed in the lesson, (2) the way that activity was framed for the participants, (3) the organization and features of the lesson segments used in completing the activity, and (4) the way the activity was brought to a close. In other words, the essential data for this research cannot simply be excerpted from the story in which it was embedded; the whole story for each lesson must be told.

The Theoretical Framework

Much of the thinking done by the researcher around this study was driven by a theoretical framework which had been largely developed prior to the data collection. As a result, one of the auxiliary objectives of this study was to scrutinize the validity of that framework within the actual classroom practice of the teachers who participated and also to fill in missing details in that framework. Further, the theoretical framework was extremely influential in terms of the evolution of the research methods used (as will become clear in chapter 3) and in terms of the way the data was perceived (see chapter 4) and interpreted (see chapter 5). Because of all of this, it is critical that key aspects of the theoretical framework be explicated in this section.

An appropriate starting point for this discussion is to trace the origin of some of the ideas which will be presented within it. The germ of the concept for this MSP investigation was generated within the context of a larger research project known as the Invisible College for Inquiry in the Secondary Schools (ICISS) – a collaboration of science education faculty and doctoral students, and practicing and pre-service teachers. As the name implies, the group charged itself with developing an understanding of inquiry grounded in the practice of secondary science classrooms. (The influence of this underlying philosophy should have come through already in this chapter.) Through this collaboration, several ‘elements of inquiry’
emerged, and one of those elements served as the seed for the growth of several key components of this theoretical framework: Inquiry is not just represented by what happens (as authors such as Eick, 2005 and Martin-Hansen, 2002 have presented it in their ‘inquiry matrices’) but, just as importantly, by how that happening is constructed.

It turns out that this ‘revelation’ concerning the nature of inquiry experienced by the ICISS members was the ‘reincarnation’ of an idea proposed by the pragmatist philosopher William James (1907 / 1981). In the following passage, Woods (2003) discusses that idea:

. . . I wish to introduce the idea of “happenings” as a possible linchpin of the experience-oriented pedagogy that pragmatist philosophers advocated. Happenings, I believe, yield a vital window to the Jamesian proposal that truth happens to an idea, but for the happening to be valuable, educators must understand the nature of and means by which to cultivate a happening. (p. 158)

The last part of Wood’s passage – that educators must become adept at being able to ‘cultivate a happening’ – ties his (and James’s) ideas to the ‘zig-zag’ emphasized by Lampert and the complex orchestration of dialogue described by O’Connor and Michaels. This gives rise to the question, though, What must a teacher do in order to be able to ‘cultivate a happening’? A little later in his article, Wood’s addresses one aspect of what is necessary: “. . . if we are in the event, we may be inclined to ask, “What’s happening?” Thus, for pragmatist philosophers, this phrase, which is an ordinary slice of everyday parlance, is shot through with profound epistemological . . . implications” (p. 158).

As with philosophers contemplating the question, “What’s happening?”, teachers attempting to cultivate a happening are significantly impacted in their ability to do so by the epistemological stance they take towards that happening. One of the first bits of progress towards developing the theoretical framework occurred with the identification of an epistemological stance that could support teachers in responding constructively to these happenings – and
in generating Lampert’s zig-zags and in orchestrating O’Connor and Michael’s complex
discourse. That epistemological stance will be presented next.

*Fallibilism*

Within the same article cited earlier, Lampert (1990) connects Lakatos’s views on the
development of mathematical knowledge with those of George Pólya. As part of that discussion,
Lampert presents the three “moral qualities” that Pólya regarded as necessary to do mathematics
(p. 31). One of these is *wise restraint*: “We should not change a belief wantonly, without some
good reason, without serious examination” (Pólya, 1954, p. 8). It is instructive to compare that
statement of Pólya’s philosophy regarding mathematical knowledge with this statement from
Cooke (2006) describing Peirce’s perspective on scientific knowledge: “But genuine inquiry can
only begin with real doubt. And real doubt occurs when something in the environment poses a
problem for the individual such that she does not know how to proceed in action” (p. 21).

For Pólya his statement represented a commitment to what he identified as the “inductive
attitude” (Lampert, 1990, p. 31); for Cooke, her statement was an attempt to represent Peirce’s
commitment to “genuine inquiry.” However, hidden within the words “real doubt” is an allusion
to an even broader aspect of Peirce’s perspective – an adherence to the philosophy of *fallibilism*
as indicated in the following passage: “I used for myself to collect ideas under the designation
*fallibilism*; and indeed the first step toward finding out is to acknowledge that you do not
satisfactorily know already; so that no blight can so surely arrest all intellectual growth as the
blight of cocksureness” (Peirce, 1931 – 1958, p. 13).

As a starting point for [briefly] exploring Peirce’s fallibilist philosophy, it is important to
note that it represents his response to *foundationalist* epistemologies; fallibilism is a *non-* or *anti-
foundationalist* epistemology (Southerland, Sinatra, & Matthews, 2001, p. 339). The label
foundationalism – applied to such epistemologies as the rationalism of Descartes or the empiricism of Locke – carries with it a “building” metaphor; as such, it indicates that, according to such epistemologies, knowledge is built off of a stable foundation of certain fundamental propositions (Colapietro, 2000, p. 47). These fundamental propositions or basic beliefs can then be used to generate other second-order justifications through inferential processes (Klein, 2005). For instance, within the rationalist tradition, certain a priori axioms serve as the fundamental propositions; within the empiricist tradition, sense perceptions assume this role.

As a non-foundationalist epistemology, fallibilism denies that such fundamental propositions can be absolutely identified. In particular, Peirce’s version of fallibilism was a response to the foundationalism of Descartes (Cooke, 2006, p. 8). One of the criticisms that Peirce launched against Cartesian foundationalism is the notion of a rationalist basis for knowledge claims: “We have no power of Introspection, but all knowledge of the internal world is derived by hypothetical reasoning from our knowledge of external facts” (Peirce, 1894, p. 213).

One of the main tenets of Peirce’s view of inquiry is “a fundamental hypothesis that there is a reality that serves as the justification for pursuing inquiry” (Hausman, 1997, p. 21). In order to transform their interactions with this reality into products of inquiry, inquirers must employ their perceptions, but these are mediated by the inquirers experience as a human being. For example, an inquirer could perceive an object of inquiry as being red, “But both our knowledge of how to use the general term [“redness”] and our justification in using the general term involve reference to the external, public world of language” (Cooke, 2006, p. 13). Thus, in deference to the empiricists, our sense perceptions cannot be viewed as an infallible source of objective knowledge. Further, the products of inquiry – explanations, theories, etc. – are constructed by the inferential processes of deduction, induction, and abduction, which are prone to errors.
Another way to explain the aspect of Peirce’s epistemology just discussed is that it transforms the basis of justifying knowledge from *self-certifying warrants* (employed in foundationalist views) to *self-corrective methods* (Colapietro, 2000, p. 47). An important implication of this is that it re-defines the *agent of inquiry*. The assumption that there are self-certifying intuitions (axioms or sense experiences) denotes that, in principle, an *individual* can be the [lone] agent of inquiry; the assumption that such self-warranting assertions are prone to error and that only the self-corrective method of experimentation can lead to more justified beliefs connotes that only the *community* can be the [final] agent of inquiry. (Although individuals can carry out inquiry, their claims only have validity in the face of evaluation and criticism by the community.) Cooke (2006) indicates the significance of this: “Peirce argues for the particular hope in the continuance of the community of inquirers and also says that we cannot act logically without a concern for the community in the long run” (p. 130).

Peirce’s fallibilist epistemology and his notion of a *community of inquirers* (COI) are two important contributions his philosophy makes to this theoretical framework. The significance of fallibilism is the imperative it gives inquirers to re-examine beliefs when the “irritation of [real] doubt” (Peirce, 1992, p. 114) warrants that. This real doubt – the nature of which was addressed earlier in the quote from Cooke – compares to the Descartian notion of *universal doubt* which Peirce railed against: “We cannot begin with complete doubt . . . this initial skepticism will be a mere self-deception, and not real doubt; and no one who follows the Cartesian method will ever be satisfied until he has formally recovered all those beliefs which in form he has given up” (pp. 28 – 29). Applied to education, this indicates that teachers should be on the lookout for moments of genuine doubt generated by students themselves – to initiate the kinds of happenings at the heart of true classroom inquiry – or create the appropriate conditions so that students will
‘accidentally’ encounter such moments of genuine doubt themselves.

There is a second implication of Peirce’s notions of a COI and of real doubt for education: The imperative to re-examine one’s beliefs in the face of real doubt generated within the community of inquirers should extend to all members of this community — including teachers in a classroom COI. It is exactly this view of the classroom COI that Chiasson (2005) is trying to convey as she describes one way in which Peirce’s ideas can be applied to pedagogy:

It is why teachers who wish to inspire learning on the part of their students must themselves possess the capability for intellectual curiosity — for engaging in genuine doubt. Peirce contends that, only when teachers themselves possess the willingness to engage in genuine doubt (or intellectual curiosity), can they inspire the will to learn in their students. (p. 214)

One could, then, imagine a classroom operating as an ideal Peircean COI, with the members of that community holding a set of beliefs about scientific phenomenon. Occasionally, those beliefs come in contact with the irritation of doubt that initiates the process of inquiry. Within the Peircean framework of inquiry, there operate two forms of dialogism which enable that inquiry to accomplish its goal (the fixation of beliefs; Peirce, 1992, p. 109). The first is the dialogism between the subject and object of inquiry. Calopietro et al. present one of the clearest statements of this form of dialogism by Peirce:

In . . . “How to Make Our Ideas Clear,” Peirce formulated his maxim in this fashion: “Consider what effects, that might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of these [experiential effects] is the whole of our conception of the object”. (Calopietro, Midtgarden, & Strand, 2005, p. 169)

This subject-object dialogism implies that the inquirer’s interaction with the object will cause the inquirer to re-conceptualize the object or to understand qualities of its nature not before realized. That aspect of this form of dialogism seems quite expected based on the goal of inquiry. What is somewhat unexpected is the other direction of that interaction — that the object of inquiry gets to
‘respond’ to this investigation of it. As Colapietro (2005) explains it, “An experiment is a conversation in which the topic being discussed is, by various contrivances, afforded the opportunity to speak back, to object to the ways it is being spoken about” (p. 416).

The second form of dialogism in Peirce’s philosophy is a type of subject – subject dialogism he labeled *tuism*. Cooke describes it this way: “For Peirce, all thought is directed necessarily toward a second person. This intersubjective idea he calls “tuism” (meaning “two” speakers, rather than the Cogito or Kant’s idea of the unity of apperception)” (Cooke, 2006, p. 135). What is important to understand about this notion is that the second person “may be the community of inquirers, an actual second person, or a future self” (p. 137). While both of Peirce’s notions of dialogism have implications for the theoretical framework being described, his notion of tuism – particularly the interpretation of it as a dialogue with one’s future self – has tremendous significance related to the way classrooms are conceptualized in this framework. (This significance will be addressed in the next sub-section.)

Before leaving Peirce’s philosophy, two further connections need to be made between it and the ideas discussed previously. The first connection is encapsulated in this statement from Colapietro (2000): “Corrigibility comes to be seen as a condition of knowledge; and actual mistakes can be seen as being of the utmost value in inquiry earnestly undertaken, rather than abstractly discussed” (p. 47). This clearly indicates how the ‘mistake stigma’ identified by Herrenkohol et al. (1999) can impede the kind of genuine inquiry Peirce saw as essential to intellectual progress. The second connection is expressed in another passage from the same article: “The course of inquiry often cuts the most circuitous paths, ones doubling back upon themselves; it makes necessary considering afresh positions thought to have been completely discredited. Moreover, it depends as much upon imagination as anything else (see, e.g., CP 1.46-47)” (p. 53).
This makes apparent how effectively a commitment to a Peircean approach to inquiry could support the generation of Lampert’s zig-zag or could lay the groundwork for the kind of complex discourse that O’Connor and Michaels favored – which is exactly the goal of the MSP structure.

**Progressive Discourse**

The main point the reader should have taken away from the preceding sub-section was that Peirce’s epistemology of fallibilism and the concomitant notions of a community of inquirers and the two forms of dialogism – particularly tuism – could serve as a strong foundation for the theoretical framework that was being developed. What was needed next was a set of ideas that would comprehensively, yet concisely delineate the practices within the community of inquirers which would allow them to adequately meet Peirce’s criteria for genuine inquiry. Certainly, additional ideas from Pólya’s description of the inductive attitude (as presented in Lampert, 1990, p. 31) provide guidance in this respect. Earlier one of Pólya’s three moral qualities (wise restraint) was introduced; the other two are “intellectual courage: we should be ready to revise any one of our beliefs” and “intellectual honesty: we should change a belief when there is a good reason to change it” (Pólya, 1954, pp. 7 – 8).

All three of Pólya’s moral qualities align with Peirce’s epistemology and perspective on inquiry and they do offer insights into the kinds of practices and attitudes essential to conducting legitimate inquiry. However, a more complete explication of such ideas can be found in the work of Bereiter (1994). Before addressing these ideas, though, it seems worthwhile to draw a parallel between Bereiter’s perspective outlined in that work and some of Peirce’s writings.

It was noted previously that Peirce partly developed his philosophy as a response to his strong disagreement with Descartes rationalism. Similarly, Bereiter’s 1994 article was his response to a philosophical position with which he did not concur: that of postmodernism or
relativism. Peirce’s dissatisfaction with rationalism centered around the issue of the way knowledge (or, from Peirce’s point of view, stable belief) was produced. Bereiter’s discontentment with postmodernism was focused on the issue of the nature of scientific knowledge itself. Bereiter points out that the post-modernist attack on the supposed objectivity of scientific knowledge shows a misunderstanding of what science is all about . . .

The key assumption supporting the scientific enterprise, therefore, is not objectivity but progressiveness. It is not necessary to believe that science is approaching some objective truth, but it is necessary to believe that today’s knowledge is better than yesterday’s. Otherwise, there seems to be no point to science.” (p. 4)

Bereiter is suggesting that the enterprise of science be looked at differently: “. . . scientific theories cannot be verified; they can at most be falsified. Progress therefore arises from continual criticism and efforts to overcome criticisms by modifying or replacing theories” (p. 5). Thus, he is proposing that instead of viewing science as a march towards objective truth, people should view science as a movement towards more justifiable knowledge claims. And that movement forward is made possible by the [progressive] discourse of science: “Sometimes people with opposing views can engage in discourse that leads to a new understanding that everyone involved agrees is superior to their previous understanding” (p. 6).

This notion of science as progressive discourse dissolves away the issues that gave the post-modernist perspective its impetus. There is no need to resort to a relativistic view of science to accommodate the ideas developed by Kuhn (1996), Lakatos (1976), etc.; there is instead a need to accept a more realistic view of how science operates. Part of adopting that view – and certainly part of enacting it – involves the acceptance of four commitments that Bereiter identifies as necessary to truly engaging in progressive discourse: (1) A commitment to work toward common understanding satisfactory to all (mutual understanding commitment);
(2) a commitment to frame questions and propositions in ways that allow evidence to be brought to bear on them (empirical testability commitment); (3) a commitment to expand the body of collectively valid propositions (expansion commitment); (4) a commitment to allow any belief to be subjected to criticism if it will advance the discourse (openness commitment). (p. 7) (One can hear echoes of Pólya’s moral qualities in these commitments – particularly the echo of intellectual courage in the openness commitment.)

If one accepts that Bereiter’s notion of progressive discourse is an appropriate metaphor for describing how science itself operates, then shouldn’t it also be seen as an appropriate metaphor for depicting how science classrooms [should] operate? This is exactly the argument being constructed here: that the practice of science classrooms should be progressive discourse and that the commitments necessary for progressive discourse should be part of the norms and rules of these classrooms. These ideas represent a central feature of the theoretical framework that was adopted for this research.

There is, though, a potential argument against the stance taken in the previous paragraph. That argument would involve pointing out that science in the classroom is different from science in the discipline in that the latter is involved with the generation of new scientific knowledge and the former is not. The remainder of that argument would suggest that since the science classroom is not involved in the production of new knowledge and the discourse participants are, in fact, dialoguing with previously-established propositions, that Bereiter’s progressive discourse metaphor really isn’t applicable. Bereiter anticipated this argument and had a response for it:

The fact that classroom discourse is unlikely to come up with ideas that advance the larger discourse in no way disqualifies it. Much of scientific discourse does not break new ground but consists of clarifications, resolutions of doubts, and the like . . . The important thing is that the local discourses be progressive in the sense that understandings are being generated that are new to the local participants and that the participants recognize as superior to their previous understanding. (p. 9)
Significantly for the larger framework, there is an alignment Bereiter’s commitments and Peirce’s view of inquiry (as described by Cooke), as indicated by the following two passages:

Ultimately, judgments of progress, then, are made *empirically*, and thus are fallible, as all judgments are. (Cooke, 2006, p. 115, her emphasis)

and

Furthermore, there are self-imposed constraints within inquiry which further the accuracy of results, e.g. improvement in taking random samples, isolating the phenomenon, and developing the fallible attitude of *openness* in questioning beliefs. (Cooke, 2006, p. 116, emphasis added)

The final point to be made, then, concerning Bereiter’s contributions to this theoretical framework is that his commitments give to the participants in a classroom COI a clear set of guidelines regarding how to engage in genuine inquiry. For the teacher in such a classroom, these commitments provide a model for developing the rules and norms of classroom interactions – an idea suggested earlier. For the students, these commitments can be appropriated to serve as a metacognitive tool for regulating their engagement in the kind of tuism that Peirce promoted – not just with the other members of the classroom COI, but with *themselves* as they both reflect on previous beliefs about a particular phenomenon and anticipate future challenges to those beliefs.

*Addressing Some Additional Influences*

When the essential features of the MSP lesson structure were presented earlier, one of those features was that as much attention needed to be paid to the *process* of solving the problem at the heart of the MSP activity as to the *content* underlying the accepted solution. An article by Karpov and Haywood (1998) presented a much more sophisticated version of the distinction the researcher was seeking to actualize through this concern. In that article, Karpov and Haywood suggest that there are two different ways to interpret Vygotsky’s meaning of the term *mediation*,
which they see as “the central concept in Vygotsky’s cognitive psychology” (p. 27). The first “refers to children’s acquisition of semiotic tools of self-regulation: self-planning, self-monitoring, self-checking, and self-evaluating. Thus, this type of mediation facilitates the development of some processes that are designated in contemporary psychological literature as metacognitive (executive) processes” (p. 27). The second “refers to children’s acquisition of cognitive tools that are necessary for solving subject-domain problems. In the rest of this discussion, we refer to this type of mediation as cognitive mediation” (p. 28).

Karpov and Haywood then used this distinction between cognitive and metacognitive mediation to highlight differences between the way that American psychologists and Soviet psychologists have approached the design of new instructional strategies. For instance, they noted that those developed in recent decades by American psychologists have focused on the metacognitive aspect of mediation (p. 29). As examples of this, they cited the mediated-learning approach used with pre-schoolers (Bright Start; Haywood, Brooks, & Burns, 1986, 1992) and the guided-discovery-in-a-community-of-learners (GDCL) approach (Brown and Campione, 1994). Subsequently, Karpov and Haywood indicated that several of the more-recognized instructional strategies constructed by Soviet researchers emphasized the cognitive aspect of mediation (p. 31). Specifically, they identified the approaches created by P. Ya. Gal’perin (1969, 1972) and V.V. Davydov (1990) as representative of this emphasis.

There are two reasons for undertaking the discussion above. The first is that Karpov and Haywood’s cognitive-metacognitive distinction seems to be superior to the researcher’s content-process distinction as a way to conceptualize that particular feature of the MSP lesson structure. Thus, this aspect could be re-formulated as proposing that an MSP activity should give us much attention to the development of metacognitive skills related to the problem-solving process (e.g.
critical self-analysis, Moreland & Carnwell, 2000) as it does to the cognitive skills.

The second reason is that it introduces two other thinkers whose ideas influenced the evolving theoretical framework underpinning this research. Gal’perin’s (1969, 1972) impact was in the form of his notion of the orienting basis of an action (OBA) which was developed as “an extension of Vygotsky’s central principle of internalization” (Haenan, 1996, p. 72). Davydov’s (1990, 2008) influence was via his emphasis on the difference between theoretical and empirical generalizations, which was an attempt to expand on and further refine Vygotsky’s views on the difference between everyday and scientific concepts (Vygotsky, 1986). Gal’perin’s and Davydov’s ideas provided critical components to the developing theoretical framework which allowed it to achieve a form compatible with Karpov and Haywood’s (1998) call for an instructional strategy that would effectively accentuate both the cognitive and meta-cognitive aspects of utilizing the mediational means available in the classroom (pp. 33 – 34). While Gal’perin’s and Davydov’s contributions to the theoretical framework did not pervade aspects of this study (e.g. the research methods employed) in the way that Peirce’s and Bereiter’s contributions did, they did have an effect worth mentioning. Gal’perin’s OBA construct provided a lens through which the researcher analyzed the way that teachers framed their lessons and Davydov’s empirical / theoretical generalization distinction offered a tool for examining the way the teachers brought the lesson to a close.

As this chapter is brought to a close, the reader is reminded that, while the main goal of this study was to characterize the interactions taking place in the enactments analyzed, a secondary goal was to use the insights gained from that characterization process as a means of advancing the theoretical framework. Thus, the intimate relationship between the research question and the theoretical framework needs to be kept in mind through the remaining chapters of this document.
Review of the Literature

In the Introduction some background to this investigation was offered to provide the proper context and this led to the presentation of the research problem and goals of the study. The remainder of that chapter was then devoted to explicating the two main components of the theoretical framework which undergird this research – Peirce’s view of inquiry and Bereiter’s notion of progressive discourse – as well as to introduce two other components which influenced the researcher’s thinking – Gal’perin’s construct of the orienting basis of an action and Davydov’s distinction between empirical and theoretical generalizations. Given the centrality of those first two components to the perspective from which the researcher viewed, analyzed, and interpreted the data for this study, it is important to begin this chapter by examining issues relevant to Peirce’s and Bereiter’s ideas. [Points related to Gal’perin’s and Davydov’s ideas will be addressed in later chapters as they become relevant to the ongoing discussion.] Once those issues have been satisfactorily explored, then the remainder of this chapter will focus on work related to studying classroom discourse and analyzing activity/participant structures, since these were two of the key areas upon which the analytical work in this study was focused.

The View of Inquiry in This Framework

A suitable starting point for this section is the following quote from Ransdell (1998):

What they [people outside of the sciences] do not understand is that its [science] success is not due to magically powerful but essentially mechanical techniques of grinding out results -- this is, unfortunately, the common view of it -- but rather to devotion to the adventurous and chance-taking spirit, informed by commitment to turning failure to success by treating mistakes as opportunities to correct one’s course rather than as signs of defeat or incompetence.

This passage – taken from the Arisbe web site (which is dedicated to exploring the ideas of C.S. Peirce) – seems to effectively capture the spirit of Peirce’s view of the scientific enterprise – particularly the process of scientific inquiry. Unfortunately, Peirce never discussed
how his notion of scientific inquiry might be translated into classroom inquiry (Colapietro, Midtgarden, & Strand, 2005), and so it has been left for those who have come after him to consider what Peircean inquiry in an educational setting might look like. Confounding such a translation is the fact that – particularly within the field of science education – there has been little in the way of consensus about the meaning of the word inquiry itself (Abd El-Khalick et al., 2004). A flavor of the magnitude of this controversy can be tasted in the following passage:

In the teaching context, inquiry seems to be used in a variety of ways without careful distinction as to the differences. It is seen both as a characteristic of a desired form of teaching and as a certain kind of activity. In either case, there is no precise operational definition and, even though the NSES has some specific teaching examples, the reader is left to create his or her own images of what constitutes this form of teaching. (Anderson, 2002, p. 3)

The purpose of this section is not to fully enter into this debate, but only to consider it sufficiently to rationalize the view of inquiry that emerges from the theoretical framework. As should be expected, that view is largely founded on the thinking of Peirce. In The Fixation of Beliefs, Peirce (1992) presents a very straightforward perspective on inquiry: “The irritation of doubt causes a struggle to attain a state of belief. I shall term this struggle inquiry . . .” (p. 114). The doubt that initiates inquiry is not the skeptic’s uncertainty of all human knowledge, but the “real felt doubt about some definite incongruity in experience” (Hausman, 1997, p. 5) which results from an inquirer’s commitment to the fallibilist epistemology. Once initiated, the process of inquiry [hopefully] leads to an end result of having the belief in question replaced with a more stable belief – a course of action that Cooke (2006) labels as the Belief-Doubt-Belief model (pp. 21 – 23). Cooke fills in some details of how that model operates within a Peircean framework:
Given the logically simplistic description of inquiry offered above, the reader might wonder why there is the need to discuss the issue of the nature of inquiry in the classroom which has swirled around within science education. The reason has to do with an aspect of the preceding passage from Cooke that is easily taken for granted: that the process of genuine or authentic inquiry is being equated with the scientific method. Peirce (1992) himself made explicit the equivalence of these two entities: “To satisfy our doubts, therefore, it is necessary that a method should be found by which our beliefs may be caused by nothing human, but by some external permanency – by something upon which our thinking has no effect . . . Such is the method of science” (p. 120). Knowing that, for Peirce, inquiry meant scientific inquiry, and recognizing that he never discussed the implications of his philosophy for education, this gives rise to the question, Would Peirce’s stance have been that authentic inquiry in schools be only that which largely replicates the kind of inquiry occurring in the discipline of science?

The issue of what constitutes authentic inquiry in the schools has become prominent as a sub-plot to the larger issue of what inquiry itself represents (Brown & Melear, 2006; Means, 1998; Schwartz, Lederman, & Crawford, 2004). For many in the science education community (e.g. Bulte, et al., 2006; Chinn & Malhorta, 2002; Zion et al., 2004), they would respond to the question above which has been directed at Peirce by answering in the affirmative – classroom inquiry is only authentic to the extent that it mirrors scientific inquiry. The following statement from Chinn and Hmelo-Silver (2002) clearly presents this stance: “Our basic premise . . . is that many inquiry activities found in schools fail to capture important characteristics of authentic scientific inquiry. By authentic inquiry, we mean the activities that scientists engage in while conducting their research” (p. 171). Largely, this stance is supported by the argument that it is
only through engagement in authentic [scientific] inquiry that students can come to a true understanding of how science works and gain the requisite cognitive skills for partaking in scientific thinking. That line of reasoning can be seen in the following passage from Chinn and Malhorta (2002):

Our central argument in this article is that many scientific inquiry tasks given to students in schools do not reflect the core attributes of authentic scientific reasoning. The cognitive processes needed to succeed at many school tasks are often qualitatively different from the cognitive processes needed to engage in real scientific research. Indeed, the epistemology of many school inquiry tasks is antithetical to the epistemology of authentic science. (p. 176)

Chinn and Malhorta themselves acknowledge a potential pitfall in expecting the activities of school inquiry to mimic those of the discipline of science: “Schools lack the time and resources to reproduce such research tasks [those of science]. Instead, educators must necessarily develop simpler tasks that can be carried out within the limitations of space, time, money, and expertise that exist in the classroom” (p. 177). This does not stop them from pointing out the vast gulf – in terms of cognitive processes and epistemological features – between typical school inquiry activities and those of real science (see pp. 180 – 182 and p. 188 for this comparison).

Certainly, one cannot entirely fault Chinn and Malhorta – and others championing this position – for wanting to try to make school scientific activities more rigorous and intellectually demanding by having them capture some of the features of disciplinary scientific activity. However, implicit within this position is an important assumption that must be questioned: That the purpose of school science is the same as the purpose of disciplinary science. It is exactly this assumption that is being scrutinized by Cobb, Wood, and Yackel (1993) in the passage below as they explore this same issue in the field of mathematics education:

The fundamental difference between a community of mature scientists and a classroom community is, in Leont’ev’s (1978) terms, that mathematical activity in school and mathematical or scientific activity in a research community are
informed by *different motives* . . . there are necessarily important differences between the classroom inquiry mathematics tradition and what we call the research mathematics tradition, and that these differences reflect *differences in the functions* of schools and research communities in society. (p. 105, italics added)

This is a very strong argument against the ‘authentic school inquiry = authentic science inquiry’ position – and an argument that has been wholly accepted as part of this research. Again, this is not to say that there isn’t some value in trying to incorporate more features of scientific inquiry into school science activities, or in interjecting some genuine scientific inquiry activities into science curricula. What is being said is that there are dangers in treating school science as an apprenticeship into real science – one of which is marginalizing any school science activity which does not model authentic scientific inquiry.

If the position discussed above seems untenable in terms of the goals and constraints of real classrooms, what alternatives exist? As part of his collaboration with an elementary school in Louisiana aimed at reforming the science teaching, Buxton (2006) was determined to create instructional materials that were representative of authentic inquiry. Before doing so, though, he found it necessary to determine what authentic inquiry means *in the context of school science*. Buxton recognized that the literature presented two views concerning this. The first one – that authentic inquiry in schools should be the same as inquiry in science – has already been discussed. Buxton labeled this as the *canonical* view (since it is based on the canons of Western science) and presented another criticism of it:

> The underlying assumptions [within the canonical view] about relevancy, meaning, and purpose in approaches . . . are based largely upon a static and de facto notion of authenticity largely determined outside the school context, without regard to what the learner (teachers or students) considers to be authentic” (p. 701)

Contrasting the canonical view was what Buxton dubbed the “youth-centered” perspective which he indicated “begins with the premise that learning is authentic when it takes as its
starting point the interests, perspectives, desires, and needs of the students” (p. 701). He cites Barton (2001), Brickhouse (1994), and Eisenhart (2001) as researchers advancing this stance.

While the canonical view may not give enough attention to what is meaningful to the teachers and students in their local situation, the youth-centered view runs the risk of not placing enough emphasis on “the reasoning processes and epistemological features of . . . authentic science” (Buxton, 2006, p. 702). In an attempt to tap into the strengths of each stance, while simultaneously mitigating their weaknesses, Buxton proposed an approach which he called contextually authentic science, which merged the other two perspectives. According to Buxton, the principles upon which this approach is founded are that . . .

. . . teachers and students must be willing to collaboratively enact a model of curriculum that attends to issues such as drawing links to family and community and including the flexibility to pursue teachable moments, a model of instruction that attends to issues such as taking inquiry outside and providing the time and resources to engage in problem posing and problem solving, and a model of assessment that attends to issues such as student choices in documenting learning and an infusion of technology for assessment. (p. 717)

While Buxton’s contextually-authentic inquiry (CAI) seems to be a reasonable synthesis of the other two perspectives on this issue, it may suffer from a couple of limitations of its own. The first is that it was developed in an elementary school setting, and it is not clear how easily this model could be transferred to other levels of schooling, particularly the secondary level with which this study is concerned. As pointed out by Keys and Bryan (2001), there has been a dearth of research at the secondary level related to inquiry (which points to one of the values of this study), and the research which has been done has indicated some issues that may impact the way a properly-grounded view of authentic inquiry is conceptualized:

The sociocultural context of . . . high school will provide both broader opportunities and, at the same time, more perceived constraints for implementing inquiry in the classroom. Broader opportunities might arise from students’ increased domain knowledge and cognitive skills; yet constraints such as time and
the mandated curriculum represent serious barriers to inquiry. (p. 638)

What does the greater accountability that teachers at the secondary level have related to covering specific state-mandated content mean with respect to their ability to design curricula that “draw[ing] links to family and community”?

The second limitation of the CAI approach is that it appears from Buxton’s description to focus much more on the box in which inquiry is packaged than what is inside the box itself (e.g. the choice of activity, whether it is done inside the classroom or outside, etc.). There is little discussion of what goes on in the thick of the investigation; how ideas are generated, communicated, and explored; and what mechanisms exist for reifying the new ‘stable beliefs’ produced by these efforts. Herrenkohl et al. (1999) have depicted inquiry as “a “cultural tool” (Wertsch, 1985) of a psychological nature, an approach to reasoning that others before us have found useful” (p. 452). If inquiry is indeed a ‘tool,’ then any meaningful explication of what is meant by authentic inquiry needs to show at least as much concern for how that tool is used as for what it is used upon.

The view of authentic inquiry adopted for this research accepts the principle from Buxton’s CAI approach that attention must be paid to both the teacher’s content objectives and the students’ interests and experiences in designing appropriate inquiry investigations. However, beyond that, this view accepts that fact that, in order for teachers to most effectively help students master the tool of inquiry, authentic experiences of this practice may involve investigations for which there is an answer already known by the teacher, not just ones where the outcome is open-ended. The reason this fact is accepted is that it will be much easier for teachers to guide students through the inquiry process if they themselves have a rich understanding of the problem space through which they must travel rather than moving through the uncharted territory typical
of canonically-authentic inquiry and also favored in Buxton’s approach [Crawford’s (2000) research provides evidence for this effect]. Further, a classroom experience is judged for this study to be authentic inquiry to the extent that the commitments of progressive discourse are upheld during the investigation and the extent to which the participants leave that experience with the sense that the knowledge they have coming out of it is superior to the knowledge they had going into it. This last criterion for judging authenticity shifts some of the focus on the process of inquiry itself; it also acknowledges that the classroom community of inquirers will have to find means for supporting the commitments of progressive discourse within the norms and culture that are extant in that community – or perhaps to adapt the norms and culture in negotiated ways to accomplish this goal.

Research Related to Bringing Progressive Discourse into the Classroom

Background on Progressive Discourse and Knowledge-Building Communities

There is a certain historical background necessary to allow any critical examination of Bereiter’s progressive discourse notion to take place. The idea of progressive discourse (PD) was initially embedded in a larger framework identified as knowledge-building communities (KBCs) and thoroughly described by Bereiter and Scardamalia (1993). As they reflect on a couple of examples of the instantiation of KBCs in actual classrooms, Bereiter and Scardamalia portray the construct this way:

What can be claimed is that the children [in these classrooms] were using scientific information to make more sense of their world, rather than simply reproducing the information, and that they were engaged in an effort to advance the state of knowledge in their group and class. That is the essential idea of a knowledge-building community. (pp. 213 – 214)

Prior to that description, Bereiter and Scardamalia outline the nine characteristics of a KBC (pp. 210 – 211). Given that some reference to these characteristics will be made in the
discussion that follows, it seems valuable for the reader to be aware of them (those not in quotes have been summarized): 1. Sustained study of topics in depth over lengths of time; 2. Focus on problems; 3. Inquiry is driven by students’ questions; 4. Explaining is the major challenge; 5. “. . . the day-to-day focus is progress toward collective goals of understanding and judgment rather than on individual learning and performance”; 6. Mostly small group work where “each group has a different task related to the central topic and plans how to distribute work among its members”; 7. Discourse is taken seriously and norms appropriate to this are established; 8. “The teacher’s own knowledge does not curtail what is to be learned or investigated”; 9. “. . . the teacher’s role shifts from standing outside the learning process and guiding it to participating actively in the learning process and leading by virtue of being a more expert learner”.

Another significant feature of the history of KBC and PD is that from the very earliest days, Bereiter and Scardamalia employed computer technology as a platform on which the KBC could be erected and as a medium through which PD could occur. As they explain this situation, “Although in principle the knowledge-building community model can function with ordinary classroom resources, most of the people experimenting with it have found computer-based technology important for maintaining the kind of information flow that the model requires” (p. 212). The ultimate realization of this technology scaffold was Bereiter and Scardamalia’s Computer Supported Intentional Learning Environment (CSILE) software that functions as a “community database [which] serves as an objectification of a group’s advancing knowledge, much like the accumulating issues of a scholarly journal” (p. 212).

**Research Stemming from KBC and PD**

Bereiter and Scardamalia’s KBC and PD, which emerged from their own research program, has also functioned as the stimulus for several other research investigations. One such
study was conducted by Oshima (1995) who was interested in how the format of the notes kept by students in the CSILE software influenced the nature of their knowledge building. Two different formats were used with two different sets of students over consecutive years; the second format was more strongly oriented towards supporting “dialogical written discourse” (p. 3). An important result of this change in format was that “knowledge transformation [as opposed to knowledge utilization] was amplified in the joint plane [as opposed to the individual work of students] in the second-year system” (p. 10). More significantly this change in the nature of the knowledge-building was associated with a change in the group dynamic of the activity system represented by the KBC:

The transition from individual as a cognitive system to a distributed system is a critical change in the activity system itself. In particular, a component “subject” of the system is no longer individual students but rather groups of students who share their knowledge as a tool for further development (Engeström, 1987, 1990). (p. 10)

Meyer and Woodruff (1997a) also studied group dynamics within a framework that included components of progressive discourse and collaborative knowledge building (p. 26). However, key aspects of their framework were additionally derived from their own notion of consensually driven explanations (Meyer & Woodruff, 1997b), which they identify as having the following features:

. . . concepts presented as related phenomena in activities (with materials) to provide experiential “knowing”; a particular sequence of the activities which requires increasing explanatory power to promote coherent reasoning; large group discussions of small group presentations to share multiple perspectives and to engage critical dialogue; and a delay in presenting scientific explanations to deter students from memorising ones in the textbook. (1997a, p. 27)

Meyer and Woodruff set up the discussion of one of the key findings from their study by indicating that sociological and ethnographic investigations of scientific research communities have proposed two different interactions within those communities (p. 28). The first, pointed out
by Dunbar (1995), occurs within individual research teams and is marked by a “high degree of mutuality, as defined by Damon and Phelps (1989), in their conversations” (p. 28). The second, recognized by Latour (1987), transpires between different research teams in the larger scientific community; this kind tends to be more “adversarial and competitive in nature” and is marked by “discourse devoted to persuasion” (p. 29). These researchers then discuss the fact that a classroom utilizing the principles of KBC, PD and consensually-driven explanations, if properly structured so as to have small-group discussions where ideas can be generated and evolved and large-group discussions where those ideas can then be vetted, can produce the same kind of knowledge building as those made possible in scientific research communities:

. . . the classroom can support both intra- and inter-laboratory type communities. Small cooperatively oriented groups are capable of providing the low risk environments to develop and nurture ideas jointly, thus evoking the processes of the intra-laboratory communities. At the same time, the whole class may be working as an inter-laboratory community that is establishing and maintaining standards and benchmarks as the class advances its understanding. (p. 29)

Recognizing that both types of interactions – the more nurturing and supportive ones found in intra-group discussions and the more challenging and critical ones indicative of inter-group discussions – are fundamental to the progress of thinking is an important insight in itself to make available to those individuals – most likely teachers – charged with establishing and guiding such communities. Further, Meyer and Woodruff showed that fashioning such interactions can afford opportunities for contributions from members of those communities who might not otherwise make them: “What was striking to us from her [the teacher’s] notes was a description of a quiet girl, Randa, who became actively involved in the later class discussions. Randa challenged some discussion from a group of boys who often dominated class discussions” (p. 36).

While the findings from this study generally support the value of adopting a framework built on the principles of KBCs and PD, Meyer and Woodruff do hint at some potential issues /
criticisms with some of those principles, even if they do not couch their statements as such. The reader should note that the last feature of Meyer and Woodruff’s consensually-driven explanations – offered above – is “a delay in presenting scientific explanations to deter students from memorising ones in the textbook”. Clearly, these researchers have a concern for eventually moving the students towards the scientifically normative explanations of phenomena – a concern which does not seem to be found in Bereiter and Scardamalia’s KBC framework.

This concern creates some potential tensions for teachers who might want to adopt the KBC framework, but who will also continue to feel an obligation to cover certain content. Those tensions were manifested in two research themes that Meyer and Woodruff indicated underlie their on-going explorations of these kinds of classroom communities. The first regards a challenge in the way teachers would approach assessment: “What are criteria for evaluating students’ explanations in school science as scientifically valid?” (p. 28). The second relates to the challenge of moving towards normative explanations of the scientific discipline while still giving merit to students’ ideas: “And, the teaching dilemma is how to link mechanisms of understanding on one hand and a set of established explanations on the other” (p. 28). Bereiter and Scardamalia do not acknowledge the potential for such conflicts in the implementation of their approach, even though adopting it would create such dilemmas for practicing teachers.

Another researcher who has incorporated significant aspects of Bereiter and Scardamalia’s ideas into his framework is Wells (1999). Much like Meyer and Woodruff, Wells has made his own contributions to the framework – in Wells case, with his focus on dialogic inquiry. Through his work with the teachers involved in the Developing Inquiring Communities in Education Project (DICEP; p. xix), Wells has added to the understanding of important features of classroom interactions that make possible KCBs, PD, and dialogic inquiry. Especially
relevant to the goals of the current research are the insights Wells provides regarding the role of *those not speaking* in determining the way the discourse moves forward in this kind of community—a role which has been under-emphasized in the discussion of other researchers. Wells hints at this role in the following statement: “… knowledge construction and theory development most frequently occur in the context of a problem of some significance and take the form of a dialogue in which solutions are proposed and responded to with additions and extensions or objections and counterproposals from others” (p. 51). Towards the end of this chapter, the reader will see how Wells elaborates on this by suggesting the cognitive and meta-cognitive responsibilities—and challenges—of being *a good listener* during dialogic inquiry.

As with Meyer and Woodruff, Wells suggests that both small group-and whole-class discussions can contribute to the progress of the discourse, although Wells recognizes slightly different aspects of this contribution than do the former researchers. With regard to the impact of small-group discussions, Wells suggests, “In talking together, children learn a great deal from each other, as they pool their ideas and explore their agreements and disagreements about the tasks in which they are engaged” (p. 114). He then immediately reflects on the potential influence of whole-class discussions, particularly the teacher’s crucial part: “The same is true of the whole class discussion in which, at the end of an activity, they reflect with their teacher upon the significance of what they have done and come to understand” (pp. 114 – 115).

Despite the implication of the modifier “dialogic” in Wells’s name for this framework, he acknowledges the importance of *written* as well as *spoken* discourse. He notes, in fact, that one of the advantages of written discourse over spoken is that the former can function as a “permanent artifact” (p. 115) which can represent “the “improvable object” that provides the focus for progressive discourse and simultaneously embodies the progress made” (p. 115).
“improvable object” – which Wells later re-labels as the “knowledge object” – is essential to the success of a KBC and is why the CSILE software was so central to Bereiter and Scardamalia’s implementations of KBCs. For Wells, this begged the asking of the question: “Can the principles underpinning CSILE be realized without such extensive (and expensive) computer support?” (p. 130). The preliminary answer – based on versions of KBCs employed by participants in the DICEP collaborative that did not rely on such technology – is that these principles can be realized as long as some other medium provides “ready accessibility of the knowledge object” (p. 130).

In another similarity to the work of Meyer and Woodruff, Wells does see the philosophy underlying Bereiter and Scardamalia’s KBC and PD as compelling, but also senses some potential problems with the application of this philosophy to the classroom. One problem is related to the five classes of knowledge that Wells identifies (pp. 62 – 65): instrumental, procedural, substantative, aesthetic, and theoretical. It is Wells’s contention that Bereiter and Scardamalia’s view of KBCs and PD emphasizes one of these at the expense of the others:

I thus concur with Bereiter and Scardamalia (1996), when they argue that “knowledge building should be the principal activity in school, but some things need to be deliberately pursued as learning objectives” (p. 502). However, I should want to point out that these “things” to be learned also involve knowledge building, though not in the theoretical mode with which these authors are chiefly concerned. (p. 111)

Because of the limitations which he perceives as resulting from such philosophical inclinations, Wells sees a tremendous research opportunity being made available: “... I am proposing ... that ... progressive discourse should ... have a central role at all levels and in all areas of the curriculum. If that is accepted, a major aim of educational research should be to explore what forms that discourse might take and what conditions enable it to occur” (p. 114). The current research is designed to take advantage of that opportunity.
A step in the direction to which Wells was pointing has been taken by Windschitl, Thompson, and Braaten (2008) within a learning environment design that they have dubbed heuristic for progressive disciplinary discourse [(HPDD), which draws as much on the notion of productive disciplinary engagement from Engle and Conant (2002) as it does on progressive discourse]. Within the HPDD framework, Windschitl et al. (2008) place a premium on the implementation of model-based inquiry (MBI; p. 314) and they equate the process of students becoming successful at engaging in this practice with the challenge of learning a new language (p. 317). Based on this comparison and adapting ideas from Gee (2002), these researchers present four conditions necessary to make possible the acquisition of such new discourses; this set includes the following: “learners need overt assistance in recognizing what to pay attention to and what constitutes background noise”; “more advanced others must also model cases of talk and action being given situated meanings within the context of practice”; and “learners need feedback when they try out combinations of words, symbols, or images within the context of new practices to test whether their hypotheses about situated meanings “work”” (p. 317).

Given the complex interactions dictated within that set of conditions, it is clear that the teacher in a classroom utilizing this framework – or any of the others discussed above – will face tremendous challenges in guiding students towards becoming legitimate participants (Lave & Wenger, 1991) in such practices. Despite this fact very little of the research within this area has focused specifically on teachers and ways that they can better support the appropriation of the skills necessary for engaging in progressive discourse. Bereiter and Scardamalia give almost no attention to this aspect of their KBCs. Perhaps this is because they see the teacher as – at best – a fellow participant in the inquiry process (see characteristic 9 of KBCs listed earlier) or – at worse – a potential impediment to this process (see characteristic 8).
Summarizing the Preceding Discussion – and Exploring a Final Issue

Before proceeding to the last piece of research to be discussed in this section, it should be noted that all of the research reviewed up to this point has direct ties to either the KBC or PD constructs. Further, in reviewing the research possessing these ties, it has been shown that at least four concerns have been raised about these two constructs – all of which surround the implementation of these ideas in the classroom. Those four concerns are (1) the focus on technology as a platform to support PD, with insufficient attention being given to classroom dialogue as that platform; (2) reconciling students’ explanations concerning a phenomenon with scientific ideas – particularly those mandated in standards-based curricula; (3) over-emphasis on theoretical knowing vs. other forms of knowing; and (4) inadequate attention to the teacher’s role in scaffolding and guiding the progressive discourse.

The final concern related to the KBC and PD constructs comes from the work of Kozulin (1996). While Kozulin’s work is not directly linked to the ideas of Bereiter and Scardamalia the way the previously-discussed research was, a key component of his writing speaks to their ideas – specifically the notion of progressive discourse. That component is Kozulin’s “life as authoring” metaphor which he offered as a principle for directing the investigations of psychology. After proposing this metaphor for application to psychology, he considered the implications of its use in education by contrasting the notion of retrospective education – which focuses on the transmission of already-developed cultural tools to students – with prospective education – which concentrates on equipping the student to solve unique new problems appropriate to the age of modernity (p. 161). Finally, Kozulin turns his attention to science and suggests an alternative to the way it is typically portrayed in educational settings based on his life-as-authoring metaphor:
Here the model provided by humanities has certain advantages over that of science. The progressivist interpretation of science presents the earlier theories either as fallacies or as approximations to the modern ones. In this context, the process of authoring is obscured by the final result. Something new always appears as better than something old. Humanities suggest an alternative model because it is impossible to say that Tolstoy is better than Shakespeare or that Hegel is better than Plato. (p. 161)

This proposal stabs right at the heart of Bereiter’s PD framework, questioning the main philosophical tenet upon which this framework is constructed. This makes the question of whether Kozulin’s proposal is a tenable one quite salient. While Kozulin effectively argues for the application of his “life as authoring” metaphor to psychology in the early parts of this chapter, his attempt to extend the metaphor to the natural sciences seems to have a flaw – a flaw which he himself makes apparent: “Whereas in the natural sciences the primary given is an object, and what is sought is the causal explanation of behavior, in the humanities the primary given is the text, and what is sought is its meaning” (p. 149). Given that science has nature as a point of reference for critically examining its ideas, it seems hard to argue that science has no means for determining whether one hypothesis or theory is better than another. If Kozulin was correct about this, then, as Bereiter (1994) points out, “there seems to be no point to science” (p. 4).

Beyond the questionable nature of its philosophical (and epistemological) premise, Kozulin’s metaphor does not seem to offer anything over Bereiter’s notion of PD in terms of moving students towards a meaningful understanding of the ideas and practices of science. As a result, it seems unnecessary to consider modifying the PD component of the theoretical framework in response to this issue. However, there are still some aspects of the concerns presented on the preceding pages that need addressed if the PD notion is to be effectively utilized in this framework. Of particular importance is a consideration of the ways in which teachers can have a more constructive role in the dialogic undertakings that are so critical to the effectiveness of a
PD-driven community of inquiry. One of the main goals of this research study is to address this concern by generating findings which will be able to fill in this void in the PD construct.

*Study of Discourse in [Science] Classrooms*

*Setting the Stage*

Given the nature of the MSP structure being investigated in this study, the following passage from van Oers (1998) articulates the importance of the topic of this section:

> . . . there is little reason to believe that area-problems or fractions are inspiring by themselves for the students. Consequently, these will not – by themselves – provoke processes of generating multiple solutions, of critically comparing solutions and arguments, or of looking for consensus. The engagement in a classroom discourse activity, inspired by a shared motive (solving the problem), is probably the basic circumstance that helps the students to coherently filter out actions, arguments, and solutions that can be taken as meaningful . . . (p. 481)

However, the optimism expressed in that passage concerning the potentially positive effect that [certain kinds of] classroom discourse could have on learning should be compared to the uncertainty concerning such an impact in these words from Mercer et al. (2004):

> As Vygotsky put it, intermental (social) activity will promote intramental (individual) intellectual development. This claim, having an obvious plausibility, has been widely accepted. However, other than our own findings presented in an earlier issue of this journal . . . any empirical evidence offered for its validity has been, at best, indirect . . . To the best of our knowledge, no direct relation has been demonstrated between encouraging students to engage in certain ways of using spoken language and their improved understanding or attainment in science. (pp. 359 – 360)

Spoiling the surprise of the ending to the story told by Mercer et al., it must be noted that these researchers *do provide* the empirical evidence to show that [certain kinds of discourse] can have a constructive influence on student learning. However, as they make clear – and as van Oers indicates in his passage – there are a set of characteristics of classroom discourse that seem to produce the most meaningful learning possible. What are those characteristics and what is the nature of the research that has made them visible? Answering those questions will be the
purpose of this section.

Tracing Some Roots . . . and Introducing a Dilemma

Interestingly, two of the ideas that serve as the foundation upon which those answers are built can be traced to the work of Vygotsky (1978, 1986). The first is that learning is not the simple transmission of knowledge from the one possessing that knowledge to the one lacking it; instead it is a social process in which a more knowledgeable other(s) guides a less knowledgeable individual(s) in the process of conceptual construction. This aspect of Vygotsky’s work has been captured in his notion of the zone of proximal development (1978, pp. 84 – 91). The second is Vygotsky’s distinction between everyday (or spontaneous) and scientific concepts (1986, pp. 146 – 209; this surfaced in the Introduction relative to Davydov’s distinction between empirical and theoretical generalization). As a backdrop for the discussion that lay ahead, it is important to note that Vygotsky – as compared to Piaget (and the proponents of conceptual change strategies based on Piaget’s ideas, e.g. Posner et al., 1982) – did not believe that, from an educational standpoint, these two types of concepts should be treated as standing in opposition to each other:

We believe that the two processes -- the development of spontaneous and nonspontaneous [i.e. scientific] concepts -- are related and constantly influence each other. They are parts of a single process: the development of concept formation which is affected by varying external and internal conditions but is essentially a unitary process, not a conflict of antagonistic, mutually exclusive forms of thinking. (1986, p. 157)

It is important to realize a further implication of this distinction from Vygotsky. The concepts representing Vygotsky’s two types do not exist in a vacuum; they are embedded in a language in which they are used. Many researchers see one of the main issues surrounding the effect of discourse in the science classroom as being the existence of two different ‘languages’ stemming from these two different types of concepts: the language of the ‘everyday world’ and the language of the ‘scientific world’ (Gee, 2005; Lemke, 1990; Mortimer & Scott, 2003; Wells,
1999; Varelas, Pappas, & Rife, 2005). As an example, in the following passage, Woodruff and Meyers (1997a) indicate how communication breakdowns can occur as a result of a failure to recognize the existence of these two languages and of misapprehensions caused by this failure:

Klaassen and Lijnse argue that such interpretations can be the result of teacher and student speaking different “languages.” Thus a misinterpretation of meaning occurs and teacher and student discourse becomes a clash of conflicting views. The authors further propose that interpretation requires finding a common ground, or “way of thinking with someone else” in order to understand meaning. (p. 26)

If one accepts the existence of two different languages in which Vygotsky’s two types of concepts become embedded, and the idea that having different participants speaking in these two different languages can lead to miscommunications, then one of the main questions related to promoting effective classroom discourse becomes, How does one respond to this set of circumstances? Gee’s (2005) response to this question seems to be that the teacher should do everything possible to discourage the use of everyday (or, as he refers to it, lifeworld) language – particularly while students are engaged in scientific activity – and to encourage the use of scientific language. He does this even while [partly] acknowledging Vygotsky’s view on the relationship between the two: “I believe there are good reasons to encourage children, even early on, to marry scientific activities with scientific ways with words, and not lifeworld languages, though lifeworld languages are obviously the starting point for the acquisition of any later social language, as Vygotsky pointed out” (p. 30). Gee defends this view by noting the way in which the use of everyday language can impede movement towards genuine scientific understanding:

It is typical of everyday language that it tends to obscure the details of causal, or other systematic, relationships among other things in favor of rather general and vague relations . . . Everyday language, in creating patterns and associations, is less careful about differences and underlying systematic relations, though these are crucial to science. (p. 33)

In a metalogue to Gee’s chapter (pp. 39 – 44; written to speak to Gee directly), Kelly
expresses a concern about this stance:

While I’m sympathetic to your desire to develop the academic languages of science, care must be taken to consider how this can be done without alienating those speaking their lifeworld language. There is some reason to believe that students do find scientific discourse as manifest in schools alienating (e.g. Lemke, 1990). (p. 40)

Later in the metologue, Kelly further explores the implications of his concern by drawing a parallel to discourse in disciplinary scientific activity. He does this by pointing to an ethnomet hodological study done by Garfinkel, Lynch, and Livingston (1981) focused on the discourses and texts produced by a scientific research team during the discovery of an optical pulsar. Kelly first notes that one of the findings from this study is “how the lifeworld discourses of the laboratory work exhibit similarities to students’ talk, in particular as contrasted with the subsequent published account” (p. 42). Further, he suggests that through such investigations, “we learn how scientists are able to translate their lab banter to persuasive texts of published accounts. They are thus multilingual in the discourses of their work” (p. 42).

Research Related to Resolving the Dilemma

There are a number of researchers working in the area of discourse in the science classroom who would agree with Kelly’s rejoinder and disagree with Gee’s position that students’ everyday language should be viewed as an impediment to learning. As an example of this, Varelas, Pappas, and Rife (2005) argue that, “As teachers we need to view our students’ prior experiences and understandings as the “capital” that we need to be investing on” (p. 162). Varelas et al. have focused on the way that intertextuality helps “the teacher and the students come together as they co-construct understandings” (pp. 158 – 159), echoing the sociocultural perspective of Vygotsky. They define intertextuality as “the juxtaposing of texts” (p. 141; in a manner similar to Gee, 1999) and further indicate that ““text” is conceived of in an expansive
way – it is more than another book that a child or teacher might refer to” (p. 141). Most importantly, they see intertextuality as a means for valuing both everyday and scientific languages in the classroom and intertwining them in the process of meaning making: “These intertextual connections allow children to play with ideas in a public way as their voices and minds mingle with those of their peers and teacher” (p. 162).

The work of Varelas et al. indicates that classroom discourse can promote meaningful learning by using intertextuality to connect the experiences of everyday activities with those of scientific [classroom] activities. As a compliment to this, a study by Brown & Spang (2008) suggests such an effect can be achieved by utilizing what they call double talk to connect the language of everyday activities with those of scientific [classroom] activities. In the following passage, they explain the meaning of this phrase:

What emerged from the data is a modeling strategy that involved the teacher’s continued use of parenthetical speaking as a way to present ideas using multiple genres of speech. We use the term “double talk” to describe how the teacher engaged in the use of parenthetical speaking as a way to present ideas from multiple linguistic positions. (p. 710)

Later, they offer this summary of the two ways that the use of double talk (by both the teacher and the students) aided in meaning making: “This hybrid discursive identity yields an approach to using scientific language that has the potential to help those who do not understand science language gain an understanding of word meanings” (p. 725). The first way is quite obvious in the passage: by building a bridge that allows students to move towards a genuine appropriation of scientific terms.

Recognizing the second way requires some additional background. Brown and Spang tapped into the work of Hymes (1972), who asserted that acquiring a comprehension of word meaning was not sufficient for fluency in a particular language and developed an explanation to
account for this fact (Brown & Spang, 2008, p. 709). A part of that explanation was the notion of *communicative competence* and, building off of this notion, Brown and Spang indicate that fluency in the use of scientific language is inhibited for many minority students because “science language has become symbolic of cultural betrayal for many minority students. As a result . . . minority] students avoid the appropriation of science language as a means to maintain cultural identity” (p. 709). They then propose that the use of double talk overcomes this obstacle by the formation of the hybrid discursive identity mentioned in the statement above.

It would seem obvious that even if a teacher adopted a position more like that of Gee – that everyday language interferes with the learning of scientific language – then, at the least, the teacher would want to help students in the process of ‘translating’ their language into that of science. There is research to indicate that this often does not happen in science classrooms (e.g. Lemke, 1990). Work done by Christie (1991) – albeit in the area of writing instruction – may help provide insight into why this might be the case. Christie prepared the lens for converging on this insight by first invoking Halliday’s (1975) notion of *register*, which Halliday defined as “a particular configuration of meanings that is associated with a particular situation . . . the register is the meaning potential that is activated by the properties of the situation” (p. 126). She then combined this with Bernstein’s (1986) distinction between *regulative* and *instructional* discourse to propose that there are at least two registers operating in any activity-based lesson:

. . . a first order, or pedagogical, register operates in such a manner that teaching-learning activity is initiated and sustained with a view to carrying forward the activity and achieving the various goals the teacher has in mind. The second order, or content, register on the other hand, has to do with the particular field of enquiry selected to constitute the content of the lesson. (Christie, 1991, p. 211)

With this lens in place, Christie proceeded to analyze the use of language within the two different registers by a large number of teachers utilizing the same writing activity. She then
presented her key finding: “It seems that teachers are more confident in promoting rather general talk about content than they are in promoting talk about a writing activity pertaining to that content” (p. 213). Assuming this same difference between a teacher’s confidence – or ability – to engage with the language of the content register versus the pedagogical register exists in science classrooms, then it could explain why teachers may be less effective than possible in helping students translate between the two languages of their classroom: While teachers may be productive in facilitating that language conversion while operating within the content register, they may be less productive when operating within the pedagogical register. Further, given that the pedagogical register is used to orient students to an activity (Gal’perin, 1969, 1992) and to re-orient them to shifts in the action during the activity, it may be that teachers are not preparing students to be cognizant of the interplay of these two languages during activities, which may hinder students from engaging in this translation process themselves while conducting them.

The Role That Triadic Dialogue May Play

Wells (1999) has noted the parallels between Christie’s framework and the one employed by Lemke (1985, 1990; interestingly, Lemke’s 1985 Using Language in the Classroom was republished in 1989 with Christie as a co-author). For instance, Wells points out that Lemke has also made a distinction between pedagogy and content in his framework, with the pedagogy aspect captured in Lemke’s activity structures and the content component represented by his thematic systems (Wells, 1999, p. 175). Based on the analysis made possible by his framework, Lemke concludes that the ineffectiveness teachers display in helping students translate between the different languages of the science classroom is not a function of a lack of confidence but of a lack of conscious awareness. He makes this point by first noting that there is often “the conflict between our commonsense ways of talking about topics and the specialized thematic patterns of
science” (p. 32). Lemke then indicates that the lack of conscious awareness largely results from the activity structure used to organize the discourse: “the way in which science is mainly taught today leaves these [two different] patterns implicit most of the time, so that the differences between the patterns rarely get talked about directly. This makes miscommunication more common and misunderstandings harder to straighten out” (p. 32).

It is upon the typical pattern of classroom discourse that Lemke heaps most of his criticisms. Following Mehan (1979), Lemke discusses the over-reliance in such discourse on a three-part dialogue structure which he labels the Question-Answer-Evaluation pattern of Triadic Dialogue (and which Mehan dubbed the Initiation-Response-Evaluation or IRE structure).

Lemke is very blunt about his view of the impact produced by the over-emphasis on this pattern:

Triadic dialogue is an activity structure whose greatest virtue is that it gives the teacher almost total control of classroom dialogue and social interaction. It tends to lead to brief answers from students and lack of student initiative in using scientific language. It is a form that is overused . . . because of a mistaken belief that it encourages maximum student participation. The level of participation it achieves is illusory: high on quantity, low on quality. (p. 168)

Lemke’s rather negative view of the role of triadic dialogue in the classroom should be compared to the stance of Wells and Nassaji (2000) on this issue:

. . . considered further, the fact that sequences of teacher-whole-class interaction should frequently start with a question is hardly surprising, since a question both proposes an issue for discussion and, because of its high level of prospectiveness, requires the recipient(s) to contribute to the issue in response. In addition, the inclusion of a follow-up move allows the teacher to work with the student’s response in a variety of ways. For this reason, this format can be an appropriate operationalization of a wide variety of tasks, even across quite different teaching ‘philosophies’. (p. 400)

Why such a striking difference in these two views on the value of triadic dialogue? Part of the reason probably is the difference in the lenses through which the samples of triadic dialogue were analyzed. Lemke’s lens was focused on the propositional content (1990, Ch. 4) and the
power relationships (1990, Ch. 5). Wells and Nassaji’s lens – being constructed partially from an activity theory (AT) perspective (2000, pp. 382 – 383) – was more focused on the function of the dialogue “as mediator of some purpose within a larger structure of joint activity” (p. 382).

Based on their AT perspective, Wells and Nassaji created codes for categorizing each move in samples of triadic dialogue; however, they particularly focused their attention on the initiating and follow-up moves (since these are the ones typically conducted by the teacher). In terms of the initiating move, they used three codes that were dependent on their inferences about the kind of information being sought in this move: “Assumed known information (where one party, almost always the teacher, already knows the answer and is concerned to discover whether students can supply it)”; “Personal information (where the information is known only to the person addressed)”; and “Negotiatory Information (where the ‘answer’ is to be reached through open-ended discussion between teacher and students together)” (pp. 384 – 385). The follow-up moves were coded based on their perceived function (as well as their prospectiveness which indicated the extent to which the move ‘expected’ a response) for which there were six categories: evaluation, justification, comment, clarification, action, and metatalk (p. 384).

In the end, Wells and Nassaji found that the nature of the impact of triadic dialogue resulted from a complex interplay of the purpose behind the initiating and follow-up moves. They suggested that “questions that introduce issues as for negotiation are more likely than known information questions to elicit substantive student contributions and to encourage a variety of perspectives” (p. 400). However, they went on to point out that this positive influence of negotiatory information questions was mitigated by the character of the follow-up response: “where student responses to questions are frequently given an evaluative follow-up, this tends to suppress extended student participation” (p. 400). Further, they noted that the use of known
information questions can still lead to more dialogic classroom interactions “if, in the follow-up move, the teacher avoids evaluation and instead requests justifications, connections or counter-arguments and allows students to self-select in making their contributions” (pp. 400 – 401).

These findings suggest that it will not be sufficient in the current study to determine the prevalence of the IRE discourse structure; it will further be necessary to consider the extent to which the instances identified contribute or fail to contribute to progressive discourse.

**A Different Type of Triadic Exchange**

The discussion of Wells and Nassaji’s work – with their notions of negotiated information and prospective follow-up moves – provide one angle on the kinds of contributions that IRE exchanges can make. The research of O’Connor and Michaels (1993, 1996) alludes to another possible contribution:

> . . . we assume that facility in particular types of complex thinking follows from repeated experience in taking on various roles and stances within recurring social contexts that support those types of intellectual give-and-take and its proto-forms . . . it requires that students engage in purposive action within a social setting.

(p. 64)

Much as Lemke has suggested (1990, p. 4), O’Connor and Michaels are indicating that “recurring social contexts” – repeated participant structures (discussed in the next section) and participant exchange frameworks – allow the interlocuters to focus more on the content of what they are saying and less on the interactional structure they are using. However, while Lemke focused his analysis along these lines on the IRE sequence, O’Connor and Michaels emphasized a different participation framework (also to be discussed in the next section) that they have labeled *revoicing* (1993, p. 322; 1996, p. 71).

Some insight into the nature of revooicing can be gained by considering its connections to two other discourse concepts that had been proposed previously. First, there is the notion of
reported speech (Voloshinov, 1973), which Wertsch (1991) describes as such: “Reported speech is the mechanism whereby one voice (the “reporting voice”) reports the utterance of another (the “reported voice”)” (p. 80). Further, he notes that “it is an arena in which one can explore issues such as the univocality or dialogicality of texts, authoritative and internally persuasive discourse, and other related issues” (p. 80). Second, there is Goffman’s (1974) concept of animation. The idea behind this concept is that an individual could “re-speak – animate in Goffman’s terms – the utterances of another, sometimes altering it in some way for the animator’s purpose” (Cazden, 2001, p. 107).

Building off these prior concepts, O’Connor and Michaels (1996) used three criteria in identifying instances of revoicing in the data they have examined: (1) a re-uttering of a previous speaker’s content by a later speaker – usually in close adjacency (temporally) to the previous speaker and often with some amount of re-formulation; (2) the presence of warranted inferences (such as so; Schiffrin, 1987) or other discourse markers such as laminator verbs (that connect the previous speaker with the revoiced propositional content; Goffman, 1981); and (3) the provision of a slot following the revoicing move for the previous speaker to approve or disapprove of the revoicing (O’Connor & Michaels, 1996, p. 93). An example of an exchange having those features would be the following (from p. 71; with additional commentary added in brackets):

Student: Well, I think that Smith’s work is really not relevant here because she only looked at adults. [Original speaker]
Teacher: So you agree with Tom then, you’re suggesting that Smith is irrelevant to language acquisition of young children? [Revoicing move with warranted inference marked by so, laminator verb (agree), and re-formulation of original proposition]
Student: Yeah. [Third slot for original speaker’s approval / disapproval]

As suggested by the above criteria, a [ideal] revoicing exchange would be a three-turn sequence, therefore making it another type of triadic dialogue, to go along with IRE sequences.
O’Connor and Michaels were certain to distinguish between the two. The first pair of differences they note (p. 82) is that (1) the teacher reserves the right to evaluate the student’s statement in the IRE exchange whereas in the revoicing sequence the student’s statement is given value from the outset and (2) the student is not afforded a follow-up turn in the IRE sequence, whereas s/he is in the revoicing sequence. Later, O’Connor and Michaels make an even more powerful statement of the distinction between the two related to the notion of meaning potentials: “Through the animation of speaking others, the revoicing participant framework makes possible an expanded and more contrapuntal set of voices and participant roles in constructing an idea than does the IRE” (p. 97).

As a result of their extensive analysis of this discourse event, O’Connor and Michaels have become convinced of the potential contribution that revoicing can make to the intellectual activity of the classroom: “the maintenance of smoothly coordinated social participation structures, the coordination of the academic task structure with ongoing social interaction, and the induction of all students into the speech activities associated with intellectual work in the envisioned community of learners” (p. 82). Further, they note that through attainment of this larger academic purpose, the revoicing move can serve these functions (culled from pp. 74 – 78):
1. clarification of content; 2. establishing the relevance of a statement; 3. introduction of new terminology for familiar ideas; 4. advance the teacher’s discussion agenda; 5. drive the discussion in another direction; 6. rebroadcasting to reach a wider audience; 7. place one student in relation to other students as holders of positions; 8. give a student credit for her / his contribution. Cazden (2001) suggests two more functions: (1) allowing the teacher to “extract the essence” of the student’s ideas while removing “the disfluencies typical of exploratory talk” and (2) changing the roles of students and teachers (e.g. teacher transitions from authority to
negotiator; pp. 90 – 91). Related to the second of Cazden’s pair, Tabak and Baumgartner (2004) also suggest that it increases the symmetry of teacher-student relationships (p. 399).

However, there is no guarantee that revoicing will have these intended consequences. Describing the experiences in her own classroom that lead to the formulation of a participant structure she called deliberately facilitated discussion, McClain (2002) offered examples of how revoicing can ‘go wrong’: “I was attempting to only influence instead of also be influenced by the students’ actions and constructions” (p. 223). What was happening is that McClain was hearing what she wanted to hear – the normative mathematical explanation – instead of hearing what the students were actually saying – and then using the revoicing move to re-formulate student ideas in the normative mathematical language. That this was indeed the case was made clear later when she explained that she “often imposed more sophisticated meanings” on students’ ideas (p. 245). The problem is that in this situation – much as in the dysfunctional IRE instances Lemke examined – much is lost in the translation – especially for the students.

O’Connor and Michaels indicate that the avoidance of such misinterpretations (and improper re-formulations) by teachers is why the third step in the revoicing move is so critical. Nonetheless, as an example from their own corpus indicates, strict adherence to the use of this third step does not ensure that such issues do not arise (pp. 84 – 85):

Michael (student):     I – I picked Alewife too [as the most likely starting station for a series of train trips] because like a lot of people like . . . like to ride on the train for a long time . . . Some people might just ride to Alewife just for the heck of it.

Godfrey (teacher):     So you made your guess based on what you know about human behavior?
               (Students in class laugh a little)

Michael:               Uhm hmm.

While O’Connor and Michaels hold this up as “further evidence of the process whereby the teacher lends authority and expertise to the student through the revoicing move” (p. 85), one
is left to wonder about the extent to which Michael’s assent in the third step truly indicates his understanding of the language translation the teacher has conducted. Further, one would assume that it is likely that students would *normally* be inclined to assent in that third step, given the power relationships that exist in most classrooms (Lemke, 1990; Enyedy et al., 2008) and that the translations provide students with “a more sophisticated reformulation to claim” (O’Connor & Michaels, 1996, p. 85). Related to this is O’Connor and Michaels assertion that, “Silence [in the place of the third move] is generally construed as agreement with the second speaker’s inference (Clark & Schaeffer, 1985)” (p. 81); while this may be true in certain social settings, one has to wonder to what extent it is valid in the classroom.

There are other concerns related to the way O’Connor and Michaels view and explore the role of revoicing in the classroom. For instance, while they see revoicing as important in supporting both the content development and social interactions of the classroom (as can be recognized in the title of their 1993 article), they have focused their analysis to a much greater extent on the social interaction component. This is a weakness shared by the work of Enyedy et al. (2008), who have undertaken the study of revoicing in multilingual classrooms. In the beginning of the article describing this study, these researchers discuss their concern for *both* the way that revoicing can serve as an *epistemic device* (p. 137; the content aspect) and the way it can influence *positioning* (p. 136; the social interaction component). However, the only time that revoicing-as-an-epistemic-device is really treated in the data and discussion sections is as it pertains to its subsequent impact on positioning.

That others have recognized this deficiency in the work connected with revoicing is apparent in this statement from Forman et al. (1998): “What is missing from the sociolinguistic analysis of discussion orchestration is the propositional content of the argument . . . when a
teacher expands a student’s utterance . . . we need to know what is important about this expansion in terms of the structure of the mathematical argument being presented” (p. 531).

In an attempt to overcome this deficiency, Forman et al. paid careful attention to the way that revoicing (both teacher and student) contributed to the construction of mathematical content during discussions and arguments in a single classroom. One of their key findings is that – in deference to the views of Scardamalia and Bereiter discussed earlier in this chapter – “the teacher’s role in orchestrating through revoicing and other means is crucial since he or she is the ultimate judge in the classroom context of the criteria necessary to establish the veridicality of a claim” (p. 533). Expanding on this later, they indicate how it is, exactly, that the teacher accomplished this complex orchestration of the social and propositional: “by recruiting attention and participation from the class, aligning students with positions through reported speech, highlighting positions through repetition, and pointing out implicit but important aspects of the explanation . . . through expansion” (p. 546).

The final issue to be raised regarding research into revoicing will lead to a broader concern about the way this kind of discourse analysis is conceptualized. On pp. 88 – 91 of their 1996 publication, O’Connor and Michaels examine a set of discourse events occurring in an inner-city elementary school in Pittsburgh; on pp. 91 – 94, they examine discourse data from some Japanese elementary schools. In neither case do they label key sequences in those events as revoicing because “the structure of these moves is quite different from the revoicing sequence detailed earlier,” despite the fact that they acknowledge that “some of the same purposes are accomplished” in these sequences (p. 91).

The issue being alluded to above is the preference for form over function, structure over substance, by most working in this area. Wertsch (1981) has addressed this situation within
psychology and has noted how this can produce very different interpretations of events from those (usually Western psychologists) adhering to the philosophy of “structuralism” than from those (usually Soviet psychologists) committed to an activity-theoretical approach:

... Soviet psychologists tend to seek constants in the functional structure of every activity... The units they use are defined on the basis of the function they fulfill rather than of any intrinsic properties they possess. In some cases this means that one and the same function can be carried out in a variety of different ways that would normally be distinguished in a structuralist approach. (p. 19)

O’Connor and Michaels (1996) seem to recognize this same philosophical difference between their work and that of Wells (1993) and the potential value of the alternative stance: “Wells (1993), invoking activity theory, takes the study of the [IRE] sequence a step further, observing that very different activities and goals can emerge from the same structure sequence” (p. 96). It seems imperative for the current research to have the flexibility – in terms of both philosophical commitments and analytical lens – to be able to see discourse events having similar structures as contributing to different functions within the classroom – and, vice versa, to recognize events having different structures as performing the same function.

Research on Additional Discourse Moves and Patterns

Nystrand and Gamoran (1990) identified a discourse move which shares a key feature with the second step in the revoicing exchange: uptake. Before presenting their description of this move, it is worth noting that this term had been a central concept in Speech Act Theory (Searle, 1969) well before its appropriation by Nystrand and Gamoran. In that framework, it referred to “the role of the interlocuter in making a given illocutionary act successful” (Duranti, 1997, p. 225) – a more general feature of conversation in which a succeeding speaker indicates her/his willingness to follow up on the intent of the action of a previous speaker. Nystrand and Gamoran’s (1990) use of the term maintains this element of a succeeding speaker integrating the
intentionality of a previous speaker into her/his current discourse – but it does so in a much more narrowly-defined context: “This process of teachers’ incorporating student answers by incorporating them into subsequent questions is called **uptake**” (p. 12; emphasis in original). (It is this re-introduction of utterances already offered by students that connects uptake to the revoicing exchange.) The pedagogical significance of this move from Nystrand and Gamoran’s perspective is its utility in allowing “teachers [to] engage students in probing discussion” (p. 12).

Connected to both revoicing and uptake – in that it gives ownership and lends value to students’ ideas – is Nystrand and Gamoran’s (1990) notion of **high-level evaluation**, “which occurs when the teacher ratifies the importance of a student response (“That’s an important point”) and allows it to modify or affect the course of the discussion in some way” (pp. 12 – 13). Engle (2006) has identified a pedagogical practice which takes this strategy one step further: *framing students as authors* (p. 485). Engle suggests this is often accomplished by including “references to the students as subjects of sentences using knowledge verbs like “explain,” “learn,” “understand,” and “figure out” (Longacre, 1976, pp. 44 – 49; cf. Levin, 1993) to position them as intellectual agents vis-à-vis the content they were learning (Engle & Conant, 2002)” (pp. 485 – 486). One of the values of this practice, according to Engle, is that it promotes transfer of content, and she proposes a couple of mechanisms through which this benefit may be gained: “Being framed as an author – rather than simply as a recipient of others’ knowledge – creates social expectations that one will be able to comment intelligently on anything related to the content that one has authored, making one answerable for that content in the future” and “being framed as an author prepares a learner to both generatively use the specific content he or she has authored so far and regularly engage in authoring ideas of all kinds, both of which would make transfer more likely” (p. 457).
Returning to the work of Nystrand and Gamoran, in a later paper with additional collaborators, they propose the idea of authentic questions which they define as “one[s] for which the asker has not prespecified an answer. Examples include requests for information as well as open-ended questions with indeterminate answers” (Nystrand, et al., 2003, p. 145; this clearly parallels Wells and Nassaji’s notion of negotiating information discussed earlier). Later they add . . .

Moreover, by allowing an indeterminate number of acceptable answers, authentic questions open the floor to students’ ideas. As such, they invite students to contribute something new to the class interaction, which in turn holds the potential for altering the trajectory of discourse in the classroom. (p. 145)

In this same paper, Nystrand and his co-workers make an important methodological statement regarding the identification of such moves as authentic questions: “In our studies, we code not questions per se but rather the interactions surrounding the questions. That is to say, our coding treats questions as sites of interaction” (p. 144). As indicated by the fact that they reference the work of Schegloff (1984) and Heritage and Roth (1995), this stance shows the influence of the conversation analysis approach (Sacks, Schegloff, & Jefferson, 1974) on their thinking. The significance of this is that in conversation analysis it is not the form of an utterance, but the function that the utterance serves in the unfolding interaction that determines its classification – thus aligning Nystrand et al’s view of how coding should be conducted with the activity-theoretical perspective addressed earlier.

This treatise can move beyond the discussion of individual discourse moves by revisiting the work of Wells and Nassaji (2000) introduced earlier. Wells and Nassaji analyzed their discourse samples at the level of exchanges, which represent combinations of discourse moves, with the requirement that, at a minimum, they are composed of an initiation-response pair (p. 383). Further, building off of the work of Berry (1981), they employed a set of exchange code categories to show how exchanges could be strung together into a larger discourse unit – the
The first exchange category is *nuclear* (p. 383) and it is this combination of moves which communicates the primary information about the topic under discussion. If the information contained in this nuclear exchange is satisfactory to complete the topic of discussion, the sequence ends there; if it is not, then one or more *bound* exchanges (p. 383) may be included to extend the conversation. (While the explanation just given may make it seem as if bound exchanges will always follow nuclear exchanges, as should be clear from the passage below, they can also precede nuclear exchanges and set the stage for the transmission of the primary information.) Wells and Nassaji (2000) recognized three sub-categories of bound exchanges:

‘Preparatory’ exchanges are used to establish communication or select a designated speaker; ‘embedded’ exchanges are used to confirm uptake or to repair various types of breakdown (e.g. ‘clarification’); while ‘dependent’ exchanges are used, for example, to give or seek additional information (‘comment’) or justification for the information already supplied (‘justification’). (p. 378)

The overall set of exchange categories became a fundamental component of the analysis framework used in this study, and so a more detailed discussion of these categories – as well as of the nature of the larger sequence unit – will be undertaken in chapter 3.

Besides providing important background for the discussion of the Research Methods, the brief overview of Wells and Nassaji’s framework sets the stage for a review of the work by Hogan, Nastasi, and Pressley (2000). In a manner similar to Wells and Nassaji, these researchers focused on the *interaction sequence* as their unit of analysis and note that this unit must be comprised of at least two speakers and at least two different discourse turns. Expanding further, Hogan et al. suggest that an interaction sequence is initiated by a “conceptual or metacognitive statement” or “question or query” by one speaker, is terminated by a speaker (either the initiator of the sequence or another speaker) doing something – “posing a new question or query,” etc. – that redirects the conversation from the focus of the initiating step, and can be of varying lengths
Their set of data led to the identification of three patterns of interaction sequences: **consensual**, **responsive**, and **elaborative** (p. 393). Most significant relative to the current study is their elaborative pattern which involved “coconstructive additions (linking a new idea to someone else’s idea or partial idea), corrections (correcting someone’s statement with a simple, undisputed statement), or dialectical exchanges (disagreeing with the prior statement and offering a counterargument)” (p. 394; although representative of a different-sized chunk of discourse, the reader should recognize parallels between this pattern and Wells and Nassaji’s dependent exchange category). One of the reasons for its significance to the current study is that Hogan et al. found that “most of the interaction sequences within the high reasoning complexity category were elaborative. When participant’s in a discussion built on one another’s contributions [such as in elaborative sequences], the reasoning sophistication increased” (p. 423).

Moving beyond even the level of [interaction] sequences, Mercer (1996) and his co-workers detected a set of three broader discourse patterns within the data from a large-scale investigation (the SLANT Project; p. 359) into various collaborative activities undertaken by children ages 5 – 12 in a multitude of classrooms (pp. 368 – 369):

1. **Disputational talk**, “which is characterized by disagreement and individualized decision making. There are few attempts to pool resources, or to offer constructive criticism of suggestions.” (p. 369)

2. **Cumulative talk**, “in which speakers build positively but uncritically on what the other has said. Partners use talk to construct a “common knowledge” by accumulation. Cumulative talk is characterized by repetitions, confirmations and elaborations.” (p. 369)

3. **Exploratory talk**, which “occurs when partners engage critically but constructively with each other’s ideas. Statements and suggestions are offered for joint consideration. These may be challenged and counterchallenged, but challenges are justified and alternative hypotheses are offered. Compared with the other two types, in exploratory talk knowledge is made more publicly accountable and reasoning is more visible in the talk. Progress then emerges from the eventual joint agreement reached. (p. 369)
One can recognize features of Hogan et al.’s elaborative interaction sequence in Mercer’s idea of exploratory talk. Another connection between the two is that much as Hogan et al. view the elaborative interaction sequence as the most influential on meaning making in the classroom, Mercer sees exploratory talk as the most useful of the three types of talk in terms of contributing to “the joint construction of knowledge by teachers and learners” (p. 369).

Interestingly, Cazden (2001, pp. 90 – 91) – in a quote presented previously – also used the phrase ‘exploratory talk’ to describe what is presumably a similar kind of discourse pattern and discussed the value of revoicing in terms of the way it allows teachers to remove “the disfluencies” typical of this kind of talk. Likewise, Wells (1999) referred to this notion when making the following point: “. . . what is clear is that . . . for exploratory talk to occur there needs to be a task that is sufficiently open-ended to elicit alternative possibilities for consideration and a classroom ethos that encourages students to engage with and share the perspectives of others in order to understand them” (p. 126). Clearly this passage indicates that the MSP lesson should serve as an important site for supporting exploratory talk; it will be important for this study to try to identify what conditions – beyond those identified above by Wells – elicit this kind of talk.

**Research Supporting the Development of a Discourse Analysis Framework**

One of the main goals of chapter 3 will be to synthesize the disparate bits of information presented in this chapter into an overall analytical framework. With that eventual goal in mind, it seems appropriate to end this sub-section by discussing two frameworks for discourse analysis which might serve as useful resources for its achievement. The first of these was found in the work of Russ et al. (2008) who were interested in finding a way to analyze the quality of students’ mechanistic reasoning during classroom conversations. To do so, they tapped into the model developed by Machamer, Darden, and Craver (2000; MDC, who work in the area of
Philosophy of Science) to describe mechanistic explanations within the realm of disciplinary science. The features of the MDC model which were transferred into Russ et al.’s discourse analysis approach are apparent in this statement:

... we use MDC’s idea that mechanisms for phenomena (seen in the termination stage) involve entities, which have particular properties and organizations, and activities among these entities that regularly take place given setup conditions. We have also translated two of the reasoning strategies from MDC’s framework into language that appropriately describes the work of students: abstract schema instantiation and chaining. (p. 511)

Based on those appropriated features, Russ et al. created nine code categories: (1) Describing the Target Phenomenon, (2) Identifying Setup Conditions, (3) Identifying Entities, (4) Identifying Activities, (5) Identifying Properties of Entities, (6) Identifying Organization of Entities, (7) Chaining: Backward and Forward, (8) Analogies, and (9) Animated Models (pp. 512 – 513). Further, they arranged these codes in a hierarchical system (which is the manner in which they were just presented) such that higher numbers corresponded to features representative of more sophisticated reasoning (pp. 513 – 514). Using this coding system, Russ et al. were able to provide evidence regarding whether there was greater or lesser amounts of mechanistic reasoning present in the discourse, identify patterns as to when these periods of greater or lesser reasoning occurred and offer conjectures to account for these patterns. While the current study is not concerned with conducting a detailed analysis of the quality of reasoning in the dialogue observed, Russ et al’s coding categories should prove useful for examining what particular aspects of certain ideas are explored at different points in the lessons and how that might correlate with the nature of the interactions and structure of activity at those points.

The other framework is much broader in scope and returns the discussion to the work of Wells and his collaborators. One of the values of Wells’s framework, which he labels as dialogic inquiry (1999) is that it largely synthesizes many of the ideas presented up to this point,
as the following passage makes apparent:

The arguments for the enactment of learning and teaching through purposeful, dialogic knowledge building have been developed at length in a number of recent works (Barnes, 1976; Mercer, 1995; Nystrand, 1997; Wells, 1999) and can be aptly summarized in the aphoristic statement that “knowledge is constructed and reconstructed in the discourse between people doing things together” (Franklin, 1996, quoted in Wells, 1999, p. 58). (Wells & Arauz, 2006, p. 415)

While some of the specific details of this framework will be treated in the next chapter, it will be worthwhile – in terms of bringing this section to a close and paving the way for the next section – to lay down some of its philosophical foundations. One of those foundations is that there are certain key pedagogical design features that must be in place for dialogic inquiry to occur. These features are (1) that teachers must establish “common knowledge . . . in an inquiry-oriented curricular unit, to ensure that students are well prepared to make good use of the open-ended and explicitly dialogic activities that are to be the heart of the unit” (Wells & Arauz, 2006, p. 419); (2) that the teacher needs to familiarize students with the discourse format so that students are “willing to take the risk of making a contribution that may not be judged by peers (or teacher) to advance the topic under discussion” (p. 420; this connects to Lemke’s views about the importance of established activity structures); and (3) that teachers choose a discourse format that allows them “to keep [the] discussion on track and, in Bereiter’s (1994) sense, progressive” (p. 420). A second foundation is obvious from the third pedagogical design feature: Wells is committed to the notion that truly meaningful classroom discourse is progressive discourse. As shall be seen in the next section, this commitment to progressive discourse predisposes Wells to think that classroom activity and dialogue should be based on a sense of cooperation not competition. The third foundation is that Wells sees the teacher as playing a central role in supporting, guiding, and maintaining dialogic inquiry; he expresses this in his analysis of the classroom activity system: “By the choice of topics to focus on and activities to engage in, by the
manner in which they relate to their students, and by the roles that they arrange for semiotic tools to play in the tasks that the students are required to carry out, teachers create different situation-types within which the texts of action are generated” (Wells, 1999, p. 180). Because of its influence on the researcher’s thinking, Wells’s dialogic inquiry framework will be revisited and further examined throughout the remainder of this document.

Study of Activity / Participant Structures

Clarifying Some Terminology

Because of its centrality to the research question, the term interaction was defined relative to the context of this study in the Introduction. Fundamentally, the goal of this research is to characterize the nature of the interactions in the MSP lessons that were videotaped during the data collection. While interesting in its own right, an interaction represents a relatively small unit of analysis. As a result, many researchers working in this area have dilated their perspective and examined how interactions are built up into larger patterns of actions / events in a classroom (Hatano & Inagaki, 1991; Herrenkohl & Guerra, 1998; Cornelius & Herrenkohl, 2004; Enyedy & Goldberg, 2004; Tabak & Baumgartner, 2004). One example of this has already been presented: Hogan et al.’s analysis of the interaction sequences in science classrooms.

Still larger patterns of classroom interactions are studied under the rubric of participant structures. The term was proposed by Philips (1972) in a book chapter discussing the results of her study of the educational difficulties experienced by the Warm Springs Indian children. This phrase appeared for the first time in the following passage and was introduced in order to provide the background necessary to understand Philips’s analytical lens:

Within the basic framework of teacher-controlled interaction, there are several possible variations in structural arrangements of interaction, which will be referred to from here on as “participant structures.” Teachers use different participant structures, or ways of arranging verbal interaction with students, for
communicating different types of educational material, and for providing variation in the presentation of the same material to hold children’s interest. (p. 377)

Her choice of words is important as structure denotes a concern for the organizational features of the milieu in which the ‘event(s)’ under investigation take place and participant indicates a focus on the “social arrangements including the concomitant rights and responsibilities” (Cornelius & Herrenkohl, 2004, p. 468) of those taking part in the event. The latter consideration is significant because it implies directing attention to the interactions between the participants – i.e. a social or socio-cultural emphasis – which has been a hallmark of studies into participant structures from the very beginning.

There is another phrase that appears in the literature describing work similar to that of Philips and Cornelius and Herrenkohl; it appears in this passage from Lemke (1990): “All social cooperation is based on participants sharing a common sense of the structure of the activity: of what’s happening, what the options are for what comes next, and who is supposed to do what. A lesson has this kind of activity structure” (p. 4, italics added). Comparing what Lemke says about activity structures to the way Cornelius and Herrenkohl describe participant structures leads one to conclude that these two different phrases really encapsulate the same aspects of the classroom milieu, with the difference being perhaps slightly different points of emphasis regarding those aspects. Since no research could be located which spoke to the relationship between these terms, it was incumbent on the researcher to address this issue in a manner consonant with the nature and goals of the current study. For this investigation, it proved valuable to distinguish between these terms, with participant structures being used to refer to aspects of the classroom milieu associated with interactional opportunities (thus aligning its use with that suggested by Philips) and with activity structures being tied to features related to the
different ‘actions’ or ‘events’ occurring during a lesson (which differentiates it from Lemke’s meaning and makes it more in line with Doyle’s (1979) notion of task structures).

As research related to the notion of participant structure expanded and became more theoretically well-articulated, a second term appeared, largely stemming from the work of Goffman (1981). That term is participation framework. As explained by O’Connor and Michaels, the notion of a participation framework unites Philips’s participant structure concept with the additional construct of animation (O’Connor & Michaels, 1993; discussed previously). Animation refers to the way in which one speaker’s discourse can automatically give identities to, open up roles for, or set constraints upon the various participants in the conversation. As O’Connor and Michaels described it, “In Goffman’s puppeteering metaphor, a speaker animates self or other as a figure or character by simple linguistic means. Through talk about each other, speakers give each other participant roles and social identities relevant to the moment” (p. 320).

Although initially difficult to discern, the distinction between participant structures and participation frameworks can be important. The participant structure is the general pattern of the social interaction (discourse event) and thus is a much more course-grained analysis of the episode being studied. The participation framework is a more fine-grained analysis, zooming in on the way the ‘action’ of the participant structure plays out moment-by-moment and what that signifies for the parts played by the actors. This difference between the two indicates that the same participant structure enacted in two different contexts (or even in two different instances of the same context), can have very different participation frameworks. As Cornelius and Herrenkohl (2004) put it, “This concept [participation framework] allows one to recognize the dynamic relations between planned structural features of the classroom and many kinds of discussions that can emerge within these purposefully chosen classroom arrangements” (p. 469).
Widening the lens back out to the broader perspective of participant structures, several interesting studies have been conducted with relevance to the current work (Inagaki, Hatano, & Morita, 1998; Crawford, Kelly, & Brown, 2000; Howe et al., 2000; Enyedy & Goldberg, 2004). Before reviewing them, it is worth orienting the reader properly to that review by presenting Horn’s (1999) description of how such studies often proceed:

. . . the examination of classroom participant structures supports the analysis of relations between students, the teacher, and various classroom activities, providing insights into the organizational possibilities and limitations for participation and learning. In studying participant structures, researchers attempt to codify (a) these relations, (b) the corresponding positions, and (c) the normative expectations for appropriate conduct. From there, interactions between participants can be highlighted and analyzed (Goffman, 1981; Hanks, 1996). (p. 3)

Some specific issues related to Horn’s description which will appear as recurring themes in the research examined will be the effectiveness of small-group versus whole-class discussion in building disciplinary knowledge and the proper role of the teacher in the discursive interactions occurring in these settings.

Investigating Small-Group vs. Whole-Class Participant Structures

Through their work Crawford, Kelly, and Brown (2000) concluded that, at the least, “whole-class discussions can be a valuable pedagogical tool with the potential to add to the effectiveness of small group work” (p. 254). The key contribution they saw for the whole-class discussion is that it allows the teacher to model the intellectual practices of scientific inquiry such as “how to articulate points of view, provide evidence for claims and recommendations, draw on knowledge of science when making choices about experimental procedures, consider the ideas of others, and achieve consensus” (p. 254). An important inference they make based on this is that whole-group discussions can serve as a valuable scaffold to allow those same intellectual practices to take place when students move to more independent small-group work.
Based on this inference, they point to a need for future research “to explore how and in what ways participation in whole-class discussions, and the modeling processes that occur through them, influence student participation and access to scientific knowledge and practice” (p. 254).

Inagaki, Hatano, and Morita (1998) are somewhat stronger in their stance related to comparing small-group to whole-class participant structures, pointing to what they feel is a clear advantage of the latter: “Student-student interactions taking place in the whole class would probably work better than those occurring in small groups, the effectiveness of which depends heavily on the constituent members’ ability (Webb, 1991)” (p. 504). They suggest that this is the case in whole-class discussions because the teacher can strategically intervene in student-student interactions “by connecting students’ arguments and by providing them with an evaluative criterion” (p. 504), whereas in small-group structures “activities . . . may go beyond the teacher’s control and result in unproductive outcomes” (p. 504).

By comparison Howe et al. (2000) have expressed a concern that whole-group discussions -- particularly the teacher’s role in it – can serve as an impediment to student comprehension in certain circumstances. The circumstance in which they were specifically interested was the process of hypothesis testing, which they saw as significant because of the confluence of conceptual and procedural knowledge occurring within this activity (p. 362). With regards to this specific context, they first suggested that the process of formulating and empirically testing a hypothesis “is not sufficient to trigger conceptual growth” and that, for the promotion of conceptual growth, “Pupils require the additional ingredient of dialogue around their conceptual knowledge, and as Piaget (1932) anticipated a highly productive form of dialogue is debate with peers who hold contrasting viewpoints” (p. 362). Continuing to work from a Piagetian framework, they assert that the constructive influence of debate on conceptual growth “can be
undermined when authority figures such as parents or teachers participate, and evidence has been obtained (e.g. Kruger, 1993) which appears to bear this out” (p. 362).

Howe et al. then designed an investigation in which they separated the process of hypothesis formulation and consensus building (which they saw as central to success within this kind of activity structure; p. 363) from the process of hypothesis testing. This allowed them to investigate the role of the teacher in these two separate processes (by splitting the students involved into four different groups depending on when and how the teacher became involved in each of the two processes; pp. 365 – 366) and to test the Piagetian prediction concerning the teacher’s potentially inhibitive influence on the first of the two. Based on a comparison of the groups representing the different kinds of teacher interventions in these processes, Howe et al. determined that “far from being a negative influence that requires preventative measures, expert guidance has something positive to contribute to conceptual growth should appropriate conditions pertain” (p. 385). They add a caveat to this conclusion by suggesting that “experts can be facilitative so long as they are not confrontational,” but there is a concern for how this finding maps “onto classroom practice, for there imposition of expert authority seems to be the norm” (p. 385). This set of ideas has a significant implication for the teacher’s role in the MSP lesson structure by suggesting that teachers must carefully balance the positive contribution of scaffolding critical thinking with the negative influence of imposing their thinking on students.

Taking into Account Teacher-Student Interactions

What is lacking in the Howe et al. study is sufficient detail about the kinds of interactions that took place between the teachers and students. One study providing such details was conducted by Au and Mason (1981) and was philosophically linked to the pioneering work of Philips. Their study looked at the different interaction patterns and indicators of productive
learning for Hawaiian students learning to read in the presence of two different teachers who, because of different background experiences, either used the same participant structures to different degrees or employed different structures. (The same children were taught by the two teachers in different lessons.) Their main finding was that one of the teachers (who had lived in Hawaii for several years) created participant structures that more closely aligned with the social experiences of students outside of school and the other teacher (who had just moved to Hawaii) created participant structures which were misaligned with these experiences. These authors concluded that “certain participation structures” – those tapping into the Hawaiian students’ cultural funds – “were consistently associated with higher levels of achievement-related student behavior than others” (p. 141). More specifically, Au and Mason proposed the balance of rights hypothesis to explain these findings. This idea states that “there should be a balance between the speaking and turntaking rights of the teacher and children, if a participation structure or lesson is to be related to higher levels of productive student behavior” (p. 142).

In their research, Tabak and Baumgartner (2004) transformed this idea of a balance of speaking and turn-taking rights into the notion of a symmetry (or asymmetry) of teacher-student relationships. Based on this notion, these authors identified three basic participant structures that they observed in classrooms where inquiry-based curricular materials were being used [Biology Guided Inquiry Learning Environments and Material Worlds Modules]. Those three structures were teacher as monitor, teacher as mentor, and teacher as partner (p. 403). The symmetry of the teacher-student relationship increased as one moved through that list with the teacher as partner being the only one Tabak and Baumgartner considered to be truly symmetrical.

Part of the evidence that these researchers produced to support the conclusion concerning the level of symmetry was the extent of use of exclusive (such as you) vs. inclusive (such as
we) pronouns. Proposing a principle similar to Au and Mason’s balance of rights hypothesis, Tabak and Baumgartner indicated that the more symmetrical the student-teacher interaction, the more conducive the structure was to student engagement in inquiry work. Indicating that the more symmetrical partner structure did this by allowing students to make the tools of science their own, Tabak and Baumgartner stated, “In this sense, the partner participant structure seems to support appropriation as well as mastery” (p. 418).

Enyedy and Goldberg (2004) applied a similar design focus on the types of pronouns used in their investigation of the inquiry practices of two teachers implementing the Global Learning through Observation to Benefit the Environment (GLOBE) curriculum. These authors note the challenge faced by teachers trying to engage their students in inquiry:

. . . the teacher and students constantly negotiate and balance between the sometimes conflicting goals: (1) having students pursue their own ideas using their own, often invented strategies; and (2) having the teacher help the students learn the concepts and skills that the teacher and curriculum, as more competent members of society and the discipline, want the students to learn. (p. 909)

As a result of their recognition of this challenge, these researchers were particularly interested in how differences in the inquiry nature of various participant structures affected content acquisition by students. To indicate that these differences – marked largely by the relative use of exclusive and inclusive pronouns – impacted content acquisition, Enyedy and Goldberg tried to correlate variations in participant structure with differential performance in the classes on a pre- and post-test content measure. While they were able to show a positive correlation in favor of the more inquiry-oriented participant structure, the validity of these correlations was weakened by (1) differences in the two classes in standardized test scores and (2) the fact that the means on both the pre- and post-test measures were so low (the post-test mean in the better-performing class was only 36%).
Horn’s (2000) research also focused on understanding how teachers might navigate a particular challenge related to implementing inquiry-oriented curriculum, although her work was done within the realm of mathematics education. The challenge of concern was, “How can classroom discourse be organized to support mathematical disagreements that (a) are intellectually productive, and (b) minimize social discomfort?” (p. 1). Horn investigated this question by reviewing videotape of two episodes from Deborah Ball’s third-grade classroom, a sample of data which has been used in other studies (e.g. Ball, 1998). Horn identified a specific participant structure – accountable argumentation – operating within these episodes, and suggested that it was the norms and expectations upheld in this participant structure which made it possible for the disagreements to be both intellectually productive and socially tolerable (p. 26). However, just as significantly, she indicated that maintaining the effectiveness of this fragile communal state required some sophisticated maneuvering – and a particular pedagogical stance – by the teacher: “In the two episodes analyzed in this paper, Ball does subtle work in deciding when to pursue or curtail students’ disagreements. Such teaching requires an acceptance of ambiguity in the classroom, something that is not comfortable for all teachers (Doyle, 1988)” (p. 27).

A retrospective point to be made about the studies reviewed so far is that, in none of them did the researchers work with the teachers involved to modify the way the teachers were interacting with their students. By comparison such an intervention by researchers was at the very heart of a study conducted by Mercer et al. (2004). They described the goal and nature of this intervention in very clear details:

A necessary condition for the implementation of the intervention programme was that teachers would effectively model and guide the development of children’s language skills. Accordingly, each participating teacher received training in the Thinking Together approach, based on videotaped examples and activities derived from earlier related projects. (pp. 363 – 364)
More specifically, their intervention was based on assumptions that echoed the ideas proposed by Christie (1991) and discussed previously: (1) That there is a difference between content and pedagogical registers and (2) that teachers are generally more comfortable leading discourse in the content register and are less confident doing so in the pedagogical register. Thus, after noting that students need guidance from teachers in learning “how to use language to enquire, reason, and consider information together, to share and negotiate their ideas, and to make joint decisions” (p. 362), Mercer et al. assert that, “This kind of guidance is not usually offered. We therefore designed a teaching programme which would enable teachers to integrate these two kinds of guidance” (p. 362). Their results indicated two positive influences of such an intervention. The first is that “the scores of target classes [where teachers received the Thinking Together training] increased significantly more than those of the control classes” (p. 371). Just as significantly, Mercer et al. noted that “Teachers report that their relationship with their class benefits, as the class gains an ethos based on shared purposes for activity and, especially, for collaboration. The class atmosphere becomes more open, interested and engaging” (p. 374).

Taking into Account Student-Student Interactions – The HEI Participant Structure

While the participant structure research discussed so far has focused more on the teacher’s role in classroom discourse – and teacher-student interactions – work done by Hatano and Inagaki (1991) and by Inagaki, Hatano, and Morita (1998) focused more on the student’s role and on student-student interactions. Central to both studies is the concept of a comprehension activity which is . . .

. . . a term for the process of achieving insight and thus . . . includes generating inferences, checking their plausibility (by seeking further information from outside or by retrieving another piece of stored information), and coordinating pieces of old and new information, all to build an enriched and coherent representation of what is going on behind a given set of information, a representation that will serve as a basis for insight. (Hatano & Inagaki, 1991,
This theoretical notion took materialized form within a participant structure that Hatano and Inagaki labeled as *Hypothesis-Experiment-Instruction* (HEI). In the HEI structure, the teacher presents the students with a problem and a set of solutions to the problem (only one of which is correct). Students are asked to consider which solution they initially support and then to vote on their choice. Following the voting, students engage in debate where they present arguments for their choice and against other choices. A re-vote is taken. Following the re-vote, the teacher presents the correct solution to the problem, either by building off of students’ ideas or presenting auxiliary information to authenticate its validity (p. 336). (Hopefully, the reader can recognize from this description at least a couple of differences between the HEI structure and the MSP structure.)

There are several important points related to this research that can be drawn from the study of the HEI structure as a comprehension activity. The first is that Hatano and Inagaki (1991) found a positive impact on student learning (p. 339) and accounted for this through the operation of two different mechanisms, both related to the whole-group nature of the participant structure. The one mechanism is based on their *socially-shared* (or distributed) *cognition* perspective (pp. 331 – 334) as they suggest “pupils’ comprehension activity [is] more effective [in the HEI structure] because it served to divide the task into several manageable parts” (p. 340). The other mechanism is . . .

. . . students’ enduring comprehension activity was pushed forward by their social, or more specifically “partisan,” motivation, as well as by cognitive or epistemic motivation. In other words, their collective attempt is not a “pure” comprehension activity but aims at winning an academic competition as well as at comprehension. (p. 340)

This “competition” mechanism leads to the second point. As envisioned by this
researcher – and as generally enacted by the participants in this study – the MSP structure is built off a sense of cooperation geared towards the common goal of solving the problem at hand. While debates may ensue as students explore alternative solutions to the problem, a sense of competition does not drive the action of the MSP structure in the way that Hatano and Inagaki indicate it does within the HEI structure. Wells (1999) – based on his framework of dialogic inquiry and, in particular, his commitment to progressive discourse (p. 417) questions the validity of Hatano and Inagaki’s notion regarding the value of competition as a driving force for learning in a broader context: “Although competition can certainly be a motivator for cooperation (Hatano & Inagaki, 1991), it seems that there is an equal, if not greater, satisfaction to be gained through working with peers toward a jointly achieved outcome” (p. 415). Based on these considerations (and also the discussion of Meyers and Woodruff’s (1997a) work presented earlier, it will be important to gauge the extent to which the interactions within MSP lessons are more cooperative or competitive in nature.

The third point is related to the impact on conceptual understanding of student-student interactions. After noting that “there have been far fewer studies on student–student discursive interactions in the classroom than teacher–student ones” (Inagaki, Hatano, and Morita, 1998, p. 504), these authors suggest that this is because “many mathematics educators and researchers seem to assume that students cannot readily learn from other students’ proposed ideas” (p. 504). Inagaki et al. then propose three reasons that educators and researchers might take this stance. One is the potential inability of students to “explore the hypothesis space extensively enough to offer reasonable alternatives” (p. 505) and another is the potential inability of students “to extract promising ideas from those offered in order to reach the correct answer” (p. 505). These two possible pitfalls seem less likely in the MSP structure (at least as it has been enacted) because of
the teacher’s capacity to provide hints to overcome the first pitfall and to use techniques (like revoicing) to model the thinking necessary to circumvent the second pitfall. However, the third reason which Inagaki, Hatano, and Morita suggest – that “in a large group many students have to remain silent, the silent students may lose interest in the discourse and thus fail to learn” (p. 505) – will likely be quite relevant in the MSP structure. Related to this ‘silent participant’ issue, these researchers found:

Mean percentages of correctly writing and manipulating a mathematical expression were 69.9 for the vocal participants versus 55.8 for the silent, and there was no statistically significant difference between these two groups by the Mann–Whitney U-test (P > 0.10). These findings indicate that not only vocal but also silent participants learned how to solve the target problem through the whole-class discussion. (pp. 516 and 518)

The final point to be made from the work of these Japanese researchers has tremendous practical relevance as it relates to an issue brought up by several teachers who participated in the current study and the pilot work that preceded it: Could lesson structures such as the MSP or HEI formats produce or strengthen misconceptions as a result of the proposal of (MSP) or support for (HEI) incorrect solutions? Citing their earlier work, Inagaki, Hatano, and Morita suggest that this may not be a serious issue: “Hatano & Inagaki (1991) argue, students can pick out plausible or promising ideas and avoid being misled by incorrect ideas offered by other students by relying on social as well as cognitive cues” (p. 505). The results of their 1998 study confirmed that this is the case in the HEI structure (pp. 519 – 522).

Engle’s (2006) notion of framing students as authors (discussed previously) may provide a strategy for helping students preferentially recall the accepted solutions. In an interview during the pilot study, when a student (Sharon, pseudonym) was asked whether she might get confused by all of the different ideas out there, she responded, “I mean even if, like, on multiple choice, you can look at the one and you’re like, ‘Well, it was Nate’s idea and then the other one was
Helen’s and Helen’s was right and Nate’s was wrong.” This suggests that granting authorship to students may help other students better distinguish between valid and invalid explanations.

*A Missing Piece – Considering the Silent Partner(s) in the Conversation*

The focus of studies of participant structures and the discourse of science classrooms has overwhelmingly been on the *speaker*, with relatively little attention being paid to the *listener*. Inagaki, Hatano, and Morita (1998) show a consideration of this issue when, at the end of their paper, they allude to the fact that the results in their HEI study may not transfer from its original sociocultural context – in Japanese mathematics classrooms – to a different sociocultural context – specifically, American mathematics classrooms – because of a difference in “socialization for listenership” (p. 524) that exists in the two cultures. As they point out, “Japanese children are good listeners, trained to listen to significant others eagerly and carefully” and “They are not frustrated nor do they become inattentive even when they have little opportunity for verbally expressing their own ideas, as long as they have some sense of participation” (p. 524). The implication is that the same kind of socialization does not occur in the United States.

Wells (1999) fully recognized the tremendous burden that rests with the listener if progressive discourse – and the framework being examined in this research – is to be effective:

> In order to contribute in a “progressive” manner to the ongoing dialogue, one has to interpret the preceding contribution in terms of the information it introduces as well as of the speaker’s stance to that information, compare that with one’s own current understanding of the issue under discussion, and then formulate a contribution that will . . . add to the common understanding achieved in the discourse so far, by extending, questioning or qualifying what has been said. (p. 107)

One piece of research sought to re-focus the attention on the listener, as well as to examine the effect that providing support for the kinds of listener responsibilities identified by Wells might have on the interactions which would unfold. Herrenkohl and Guerra (1998) strove to accomplish these objectives through the intentional manipulation of the participant structures
in two different classrooms. In one classroom, they provided intellectual roles (p. 441) to students conducting group presentations (ROLES), and in the other classroom they supplied such roles to both the presenters and the audience members (ROLE + AUD). For both sets of roles, the teachers helped scaffold the cognitive skills necessary to assume these roles, while still allowing students autonomy over the way the roles were individually enacted. With regard to the audience roles, Herrenkohl and Guerra built the cognitive supports around what they saw as the three fundamental features of Hatano and Inagaki’s comprehension activity (discussed above): (1) monitoring comprehension, (2) challenging others’ perspectives and claims, and (3) coordinating theories with evidence.

Herrenkohl and Guerra conducted a discourse analysis of the episodes – as determined through a number of activity settings criteria established by Tharp and Gallimore (1988) – of several lessons from each of the two class conditions. They classified each of the student and teacher discourse events in those lessons into one of four categories: The three role functions listed above and then the additional category negotiating a shared understanding of classroom procedures and standards (Herrenkohl & Guerra, 1998, p. 450). Their most significant finding from this analysis was that students engaged in more episodes of all four types of participation in the AUD + ROLES condition. Overall, this indicated that students were much more involved in the types of discourse that represent enactment of the disciplinary practices of science. As a powerful way of summing up these results, the authors state that, “. . . the very form of participation was different in the two classes [ROLES vs. ROLES + AUD ROLES]” (p. 465). This finding clearly points to the need for the current study to consider what kind of structure teachers could use to support students in this pivotal aspect of their participation in the interactions taking place within the MSP lessons.
Research Methods

General Features of the Study

As first presented in the Introduction, the research question that drove this study was, *What is the nature of the interactions that occur during Multiple Solution Pathway (MSP) lessons and how are those interactions related to the structure of activity and the way in which ideas are explored within those lessons?* What this chapter will accomplish is to lay out the process by which this question was studied, beginning with a delineation of the more general characteristics of the research approach employed.

The first point to be made about the features of this study is that, while some quantitative information will be presented (e.g. the frequency of certain discourse moves within different segments of the lessons analyzed), this work was mainly *qualitative* in nature. As defined by Denzin and Lincoln (2003),

> Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world . . . qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or to interpret phenomena in terms of the meaning people bring to them. (p. 4)

The “natural settings” in which this study took place were the classrooms of the teachers who participated in this project (see below for a brief sketch of the schools in which these classrooms were located), and, within those settings, the researcher interviewed both the teacher and a selection of students, and videotaped the participants as they engaged in the problem-solving activity at the core of each lesson. The researcher used the interview and video data collected to try to “make sense of” or “interpret” what the interactions were within these lessons, how they were involved in the process of examining different solutions to the problems posed, and how they were connected to the different activity segments within the lessons.
The depiction provided above indicates that – beyond its identification as a qualitative investigation – this study must also be labeled by the terms exploratory and descriptive. It will explore what occurs when different teachers enact their visions of what an MSP lesson ‘looks like’; how ideas are generated, vetted, tested, and eventually either discarded or accepted; and how those actions become encapsulated in the structure of activity. Then, the findings from that exploratory process will be used to create a description of the manner in which the MSP lessons unfolded in the various classrooms – a description anchored in the theoretical framework (largely the notion of progressive discourse and its commitments) presented in the Introduction.

Discussion of the Participants and Data Corpus

Since the teacher participants are central figures in the data collected for this study, drawing meaning from and interpreting that data will depend on ‘knowing’ them and understanding how their involvement in this study was organized. Initially, there were fourteen teachers who agreed to have data collected in their classrooms. Five of those individuals lost interest in participating in the study, so data was actually collected from nine different teachers. While this author made every attempt possible to procure participants in such a way as to give the broadest range of teacher contexts possible and to match teachers based on various characteristics (e.g. subject, gender, years of experience), in the end, participation was limited by the schools and teachers to which the researcher had access. Thus this research utilized a convenience sample (Marshall & Rossman, 2006). For instance, two of the participants teach at the school from which the researcher graduated; one was mentored by the researcher; one was supervised during a pre-student teaching experience by the researcher. While the existence of such personal histories of affiliation with the researcher obviously constrains the conclusions which can be made at the end of this study, it also allowed more open discussions concerning
how to implement the principles of progressive discourse in the lessons.

Within the larger (ICISS) research program in which this study is nested, one of the objectives is to capture inquiry practices across different scientific disciplines. Thus, the initial set of data included videotapes of lessons taught in five different chemistry classrooms, two different biology classrooms (one was an elective kinesiology class in which the instructor was certified in biology), and two different physics classrooms. Closer examination of this diverse set of data led to a decision to focus the analysis for this dissertation study on the data collected in the five chemistry classrooms, to the exclusion of the other two sets of data (biology and physics); two justifications for that decision will be provided.

The first justification is that both the researcher and co-coder of the discourse data have undergraduate degrees in chemistry (with the co-coder having worked six years as a research chemist), and so an emphasis on the chemistry data allowed a richer analysis of the conceptual content of that data to be achieved. Further, this disciplinary knowledge made it less likely that important information related to the way different ideas were generated, developed, and critically examined would be overlooked.

The second justification is that there was a significant difference in the participant structure (Philips, 1972) between the three sets of lessons: in the five chemistry lessons, the majority of the activity time was spent in whole-class discussions (although, as will be discussed in chapter 4, there were some variations in this from teacher to teacher); in the biology and physics lessons, the majority of the time was spent in independent small-group work devoted to solving the problem. As a result, it would have been difficult to have any discussion across the chemistry and the biology / physics lessons in terms of similarities and differences in the nature of the interactions. Related to this second justification, Wells (2008) has noted that, “while
occurring fairly frequently in small inquiry groups, Hatano and Inagaki’s three discourse practices -- clarification, disputation, and coordinating evidence with theory – have been found less likely to occur in whole class discussion” (p. 344). (Hatano and Inagaki’s work was discussed in the Literature Review.) By focusing on the chemistry data, therefore, it was possible to determine whether the pattern indicated by Wells still held in these MSP lessons.

In the end, then, for this study, there were five different teacher participants representing four different schools across the state of Pennsylvania. Information concerning those participants and their schools is presented in the table on the next page.

Once a teacher had agreed to participate in the study, s/he was sent an e-mail by the researcher in which (1) s/he was thanked for being willing to participate, (2) an initial meeting was set up with the researcher, and (3) an attached word file – the ‘Dead End Information Packet’ – was offered to begin induction into the research. The Dead End Information Packet begins by presenting a passage from Thomas Goetz’s (2007) article Freeing the Dark Data of Failed Scientific Experiments which discusses the notion of dead ends in scientific research and the potential value of reporting the data from such events. It then proceeds through six sections of ideas: (1) Introduction, in which the importance of discourse in science classrooms is addressed; (2) Exploratory Talk, in which Mercer’s research is discussed and his styles of dialogue are described; (3) The Dead End as a Structure for Building Exploratory Talk, in which the dead end is explained in a general way; (4) Components of the Dead End, in which a more detailed description of the nature and features of the dead end is presented; (5) Adding a Few Caveats, in which potential misinterpretations of the idea behind the dead end notion are addressed; and (6) Contributing to a Higher Purpose, in which Bereiter’s progressive discourse view and associated commitments are outlined. (The complete packet is found in Appendix C.)
### Table 1 – Basic Teacher Participant ‘Biographical’ Information

<table>
<thead>
<tr>
<th>Name (Pseudonym)</th>
<th>Gender</th>
<th>Years Experience</th>
<th>Subject / Courses Observed</th>
<th>General School Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
<td>F</td>
<td>15</td>
<td>Chemistry I [a heterogeneously-grouped introductory chemistry course]</td>
<td>Serves a residential area in eastern Pennsylvania; typical graduating classes range between 160 and 180 students; very limited ethnic diversity (less than 1% of student population is non-Caucasian)</td>
</tr>
<tr>
<td>Hannah</td>
<td>F</td>
<td>3</td>
<td>Chemistry I [same as above]</td>
<td>Same school as Sandy</td>
</tr>
<tr>
<td>Sarah</td>
<td>F</td>
<td>2</td>
<td>Academic Chemistry [students are more homogeneously grouped by (high) ability]</td>
<td>Located near a metropolitan area in south central Pennsylvania; averages ~285 students per grade level; around 10% non-Caucasian student population</td>
</tr>
<tr>
<td>Nancy</td>
<td>F</td>
<td>12</td>
<td>Regular and Accelerated Chemistry [students grouped by lower (Reg) and higher (Acc) academic ability]</td>
<td>Serves a rural area in central Pennsylvania; small school with graduating classes of ~70 students; less than 1% non-Caucasian students in the school</td>
</tr>
<tr>
<td>Marty</td>
<td>M</td>
<td>8</td>
<td>Honors Chemistry [students are more homogeneously grouped by (high) ability]</td>
<td>Located in north central Pennsylvania; a small school district, with graduating classes of ~160 students; less than 1% non-Caucasian students in the school</td>
</tr>
</tbody>
</table>
An initial meeting was conducted as soon as possible once a teacher had agreed to participate. At the initial meeting, the researcher set the stage for the teacher’s involvement in this work by making three points clear before any discussion of the specifics of the research was undertaken. The first point was that the researcher wanted to work with the teacher in order to make the research as minimally disruptive as possible. The second point was that the research was not intended to be evaluative of the teacher in any way. The idea was for the researcher to collect several examples of the MSP lesson in order to try to understand the kinds of interactions that occurred in these lessons and what conditions may have produced those interactions.

The third – and most important – point was that the researcher was not coming into the teacher’s classroom to tell her/him what to do. It was noted that the Dead End Information Packet represented a set of tentative ideas about how to structure certain classroom experiences and that the validity of this set of ideas needed to be jointly explored by the teacher-participants and the researcher towards a goal of understanding what works best and why. In addressing this point, the researcher was trying to make clear that this project was to represent a true collaborative. As such, it was important that the teachers understood that the researcher fully expected to learn something from the teachers – perhaps as much or more than they learned from him.

A final point needs to be made about these initial meetings: By the time the researcher had gotten to the stage of conducting these meetings, the focus of this study had expanded from examining the limited number of dead end events that might occur in the videotaped lessons to the larger view of the way students and teachers explored multiple solution pathways within those lessons. This broader perspective was shared with the participants in the initial meetings and the researcher tried to make clear the connections between the smaller dead end aspect and the larger MSP structure. Specifically, a great deal of attention was paid to Bereiter’s notion of
progressive discourse and the meaning of the four commitments in the context of classroom discussions of scientific phenomenon.

The other set of participants in this study were the students in the classes which were videotaped. From each of those classes, two students were chosen for further participation in this study in the form of post-lesson interviews; those students were chosen based on one of three criteria. The first is that the researcher looked for students who made important contributions during the MSP lesson – e.g. they proposed the ‘correct’ solution or one of the alternatives. If numerous students made such contributions, then the selections were made based on pairing interviewees based on differences in performance level in the class (criteria 2) or normal levels of participation in the class (criteria 3). When basing the selections on either of the last two criteria, the researcher deferred to the teacher’s knowledge of the class in suggesting students who could be paired on these characteristics and in picking students who might be open to being interviewed. A table listing the student interviewees (using pseudonyms) and the reason for selecting them to be interviewed is found on the next page.

Data Collected

Interview Data

Rationale for Inclusion of This Data

The central data for answering the research question will be that which is produced by the analysis of the videotapes of the lessons taught by the five teacher participants (a discussion of that analysis will occur in subsequent sections). In the conversation analysis approach to discourse interpretation (Schegloff, Jefferson, & Sacks, 1977), this would be the only data from which the kind of analytical inferences needed to complete this study’s line of inquiry could be drawn. Following that approach, one could not, for instance, talk to the participants following a
### Table 2 – List of Students Interviewed

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Teacher / Class Period</th>
<th>Reason Student Was Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>Sandy / Pd 3 Chemistry I</td>
<td>Exhibits high level of participation</td>
</tr>
<tr>
<td>Helen</td>
<td>Sandy / Pd 3 Chemistry I</td>
<td>Exhibits low level of participation</td>
</tr>
<tr>
<td>Matt</td>
<td>Hannah / Pd 1 Chemistry I</td>
<td>Proposed the ‘correct’ solution</td>
</tr>
<tr>
<td>Ian</td>
<td>Hannah / Pd 1 Chemistry I</td>
<td>Part of group proposing alternative solution</td>
</tr>
<tr>
<td>Susan</td>
<td>Hannah / Pd 3 Chemistry I</td>
<td>Higher performing student in the class</td>
</tr>
<tr>
<td>Leanne</td>
<td>Hannah / Pd 3 Chemistry I</td>
<td>Lower performing student in the class</td>
</tr>
<tr>
<td>John</td>
<td>Sarah / Pd 1 Academic Chem</td>
<td>Proposed the ‘correct’ solution</td>
</tr>
<tr>
<td>Alexis</td>
<td>Sarah / Pd 1 Academic Chem</td>
<td>Initially confused by ‘correct’ solution</td>
</tr>
<tr>
<td>James</td>
<td>Sarah / Pd 5A Academic Chem</td>
<td>Exhibits high level of participation</td>
</tr>
<tr>
<td>Chloe</td>
<td>Sarah / Pd 5A Academic Chem</td>
<td>Exhibits low level of participation</td>
</tr>
<tr>
<td>Karen</td>
<td>Nancy / Pd 3 Acc. Chem</td>
<td>Proposed the ‘correct’ solution</td>
</tr>
<tr>
<td>Cole</td>
<td>Nancy / Pd 3 Acc. Chem</td>
<td>Initially confused by ‘correct’ solution</td>
</tr>
<tr>
<td>Kathy</td>
<td>Nancy / Pd 6 Regular Chem</td>
<td>Proposed the ‘correct’ solution</td>
</tr>
<tr>
<td>Tim</td>
<td>Nancy / Pd 6 Regular Chem</td>
<td>Made interesting contributions to discussion</td>
</tr>
<tr>
<td>Betsy</td>
<td>Marty / Pd 4 Honors Chem</td>
<td>Bright student who seemed to struggle with ambiguity in parts of activity</td>
</tr>
<tr>
<td>Troy</td>
<td>Marty / Pd 4 Honors Chem</td>
<td>Part of group researcher audiotaped during two phases of the lesson</td>
</tr>
<tr>
<td>Mandy</td>
<td>Marty / Pd 6 Honors Chem</td>
<td>Part of group researcher audiotaped during two phases of the lesson</td>
</tr>
<tr>
<td>Sally</td>
<td>Marty / Pd 6 Honors Chem</td>
<td>Very active participant in the activities, but seemed to struggle with the concepts</td>
</tr>
</tbody>
</table>
discourse event to gain insights into why the event evolved the way that it did. Drew and Heritage (1992) explain the rationale behind this methodological philosophy: “The direct focus on recorded conduct has the advantage that it cuts across the basic problems associated with the gap between beliefs and action and between what people say and what they do” (p. 5).

While accepting of the logic behind this methodological stance, the researcher felt it valuable to obtain interview information from several participants in each class in which a lesson was videotaped. The motivation for collecting this secondary data set was the recognition that the videotapes will capture just a single temporal ‘slice’ of a classroom activity system (Engestrom, 1999). Therefore, these interviews were seen as an opportunity to gain insights from participants about features of those activity systems which have been built up over time – such as the norms and rules for participation and shared experiences – and which might have a bearing on the manner in which the interactions unfolded in the lessons. For example, during a student interview the researcher learned that there were a set of homework problems given in Hannah’s class a week or so prior to the videotaped lesson that impacted a pair of interactions between that student and Hannah – including a key interaction involving a solution proposal.

Before proceeding it is important to emphasize that these interviews were treated as a secondary source of data for this study. As such, the information obtained through them was used to fill in details in larger points derived from the analysis of the video. Further, the information was used to support or corroborate conclusions to which the video data first pointed.

*Features of the Interview Protocols*

For each teacher participant, a minimum of three interviews was conducted: two prior to the lesson and one following it. The content of those interviews was focused on three major topic categories: (1) views / beliefs concerning best practices and the nature of scientific
knowledge; (2) planned enactment of the MSP lesson; and (3) actual enactment of the MSP lesson. The goal was that each interview would address one of those three topic categories, with the two pre-lesson interviews addressing (1) and (2) and the post-lesson interview focused on (3). Each of those three major topic categories had at least five main questions (Rubin & Rubin, 2005, p. 135) devoted to it (category 3 had six such questions for it). Appendix D organizes this information and presents the entire set of main questions used in the teacher interviews.

The format of these interviews was largely based on the responsive interviewing framework developed by Herb and Irene Rubin (Rubin & Rubin, 2005). A core element of this framework is that interviews are treated as “conversations in which a researcher gently guides a conversational partner in an extended discussion” (p. 4). One of the ways to keep the interview more conversational in nature is to conduct it in a semi-structured format (pp. 4 – 5) and so that was the style adopted in this research. To that end, the researcher allowed responses by the teachers to dictate the order through which the questions in a particular category were navigated, used probe questions (p. 137) to elicit further details about specific responses, often asked follow-up questions (p. 183) in later interviews to revisit ideas from previous conversations, and would sometimes bring in questions planned for later interviews if they were seen to connect with current conversations.

One feature of the post-lesson interviews requires particular attention. Going into the study, the researcher had intended to mark key events related to the implementation (or failure of implementation) of the principles of progressive discourse as critical junctures in the live video capture of the lesson. [This element can be noted in C.5 of Appendix D.] The plan then was to discuss those critical junctures in the post-lesson interviews with teachers in a stimulated recall format (Calderhead, 1981; Stough, 2001) in which teachers would be asked questions related to
their decision-making process during those critical junctures. However, once the data collection began, the need to specifically focus on these critical junctures became less significant as teachers often addressed the key events in responses to other questions such as, ‘How do you feel the lesson went?’ and ‘What are the challenges of conducting this kind of lesson?’ There were only two occasions in which the researcher brought up such critical junctures before they were introduced into the interview conversation by the teachers (one in Nancy’s interview 4 related to a student’s solution proposal and one in Hannah’s interview 4 related to a discussion about the testing process), and the important aspects of those events were able to be addressed without having to review the videotape. In general the data related to these critical junctures has become less essential to answering the research question than was anticipated at the outset of this study.

The teacher interviews lasted 20 – 40 minutes and were conducted during planning periods or after school hours. The total number of interviews for each teacher (ranging from three with Sandy and Sarah to five with Nancy and Marty) was determined by the time available in each interview block and by the time required to get through the entire set of main questions. Each interview was completely transcribed by the researcher and broken down into topic sections to keep track of interview segments which were related to each other. There were 278 pages of teacher interview transcripts.

The criteria for selecting students for interviewing were offered in the previous section. Once these student interviewees were selected, a single post-lesson interview was conducted. That interview either took place on the day of the lesson – the preferred case – or the next day – in the event that the lesson occurred at the end of the day or that the student had no open time slots the same day. The student interviews tended to be shorter than the teacher interviews, ranging in duration from around eleven minutes up to around 22 minutes.
The student interview questions were developed from a list of essential issues which the researcher was interested in discussing with the students: (1) The nature of scientific knowledge, particularly whether that knowledge can be ‘proven’ and what role errors / mistakes may play in generating that knowledge; (2) the nature of knowledge in the science classroom – particularly whether that knowledge is unchanging – and the role that errors / mistakes may play in building up that knowledge; (3) alignment between science in this classroom and disciplinary science; (4) the cultural norms of the classroom, particularly how similar the MSP lesson is to typical lessons and whether practices related to the progressive discourse commitment were common; (5) recollection of different solutions proposed (including the student’s own and those of other students) and of the efficacy of those solutions; (6) conceptual understanding; (7) students views about the value of doing the lesson this way compared to other alternatives (particularly a more traditional lecture); (8) concerns with misconceptions being implanted in students’ heads.

In order to keep the interviews to a reasonable length and to maintain consistency related to the content of the information gathered, a set of core questions was posed to all of the student interviewees. Depending on their responses, auxiliary questions related to essential issues were also asked. (The entire set of core questions – presented in regular font – and auxiliary questions – presented in italicized font – are found in Appendix E, along with the number of students to which each auxiliary question was put forward.) Probe questions were kept to a minimum in order to streamline the interviews.

As with the teacher interviews, the student interviews were completely transcribed by the researcher. The content of the transcripts was organized in a manner similar to the teacher interviews, with the additional feature that all of the interviews for the students of a particular teacher were put together in a single document. There were 196 pages of student interview transcripts.
Video Data

Delineating the Data Corpus and Collection Procedure

For each of the five chemistry teachers involved, a single lesson representing her/his attempt to instantiate the MSP structure was videotaped, although that single lesson was enacted in from two to four classes (see the table below) depending on her/his teaching responsibilities (and each enactment was videotaped). For Sandy and Sarah, all of their enactments took a single period to complete. For Hannah, Nancy, and Marty, each of their enactments occurred over the course of two class periods, with Nancy and Marty splitting those two class periods over two school days, and Hannah completing each of her enactments in a single day owing to the availability of double-period classes in her school’s teaching cycle.

Table 3 – Number of MSP-structure Enactments by Teacher

<table>
<thead>
<tr>
<th>Teacher</th>
<th># of Enactments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
<td>3</td>
</tr>
<tr>
<td>Hannah</td>
<td>3</td>
</tr>
<tr>
<td>Sarah</td>
<td>4</td>
</tr>
<tr>
<td>Nancy</td>
<td>2</td>
</tr>
<tr>
<td>Marty</td>
<td>2</td>
</tr>
</tbody>
</table>

All of the enactments were videotaped by the researcher and captured on a mini digital video tape (most on a single tape; some over two different tapes), then digitized and converted into a QuickTime® file. The discourse (along with other visible means of communication, such as hand gestures) was completely transcribed for all fourteen enactments. Additionally, each of these fourteen enactments was analyzed using a discourse coding procedure to be described in subsequent sections. Examining all fourteen enactments allowed for the most complete picture
of the different kinds of interactions that were possible as different teachers conducted the MSP lesson structure with different classes of students. However, in the case where any kind of numerical comparisons (i.e. in the frequency of certain discourse moves) was to be made across different teachers, only the data from the first two lessons for each teacher was included to make the circumstances of the enactments as similar as possible. This would mitigate any advantages gained by teachers having more experience with conducting the particular lesson.

The entire corpus of video data was composed of the following: 503 pages of video transcripts (with individual transcripts ranging in length from 21 pages for Sarah’s period 7 lesson to 64 pages for Hannah’s period 3 lesson) and 360 pages of discourse coding documents (ranging in length from 14 pages for Sandy’s period 3 lesson to 49 pages for Hannah’s period 3 lesson).

Data Analysis

Interview Analysis

After transcription of all of the interviews (both teacher and student) was completed, the researcher read through all of the interviews in two sets – going through all of the teacher interviews first, then through all of the student interviews. Within those sets, the interviews were read in sub-sets by examining all of the interviews for one teacher before reading any interviews for another teacher, and by reading all of the interviews for the students of a particular teacher before moving on to any other student interviews.

During this first reading process, analytical notes were added to the interviews to highlight statements by the interviewees which seemed to relate to the issues indicated by the theoretical framework of this study, such as what role the interviewee saw for error / mistakes in the science classroom or the relationship between typical interactional practices in the particular classroom and the kinds of interactions which occurred during the sample MSP lesson. After
this process of embedding analytical notes was completed for the entire corpus of interview data, recurring themes – such as the [limited] applicability of the MSP lesson structure to different contexts in the teacher interviews and the view of the scientific inquiry process as [mostly random] trial-and-error in the student interviews – were identified and instances of these themes were noted in the interview transcripts. The locations within the transcripts of all instances related to a particular theme were recorded in a document titled *Overall Analysis of the MSP Lessons* for ease of access.

Because the interview data was to be used only as a secondary source of data, a full coding system was not developed for this data. Thus, the analysis of the interviews represented partial fulfillment of the procedure for *The First Phase of Analysis* as outlined on pp. 201 – 223 of Rubin and Rubin (2005).

*Video Analysis*

Developing a basis for determining how to conduct the video analysis began by considering Gee and Green’s (1998) notion of a *logic of inquiry*. This notion suggests that the selection of both the theoretical framework and the research methods should be done in such a way as to produce a compatible, coherent whole: “. . . we view this knowledge [of the relationship between theory and method in a study] as critical, since each decision about method implicates the use of particular theories and the exclusion of others, and each decision about theory entails related decisions about method” (p. 121). It is crucial to note, however, that what Gee and Green are discussing within this logic-of-inquiry principle is not simply a dyadic relationship of theory and method, but a triadic relationship of *purpose* (research question), theory and method. Since it is [usually] the question that drives the research, then the real objective of considering this principle is determining the best way to align the theory and
methods with that question. The alignment between the question and the theory was laid out in the *Introduction*; in this sub-section, the objective will be to explicate the way that the research methods were designed to show correspondence with the question.

The second half of the research question concerns how the interactions within the MSP lessons are related to the way ideas are explored within the structure of activity in those lessons. As a first step towards bringing the question and the methods for answering it into sync, it seemed necessary to develop a video-analysis framework which made the structure of activity salient. The basis for constructing such a framework was derived from a format for analyzing classroom discourse which was outlined by Wells (1999). Wells’s format was produced from a synthesis of ideas from *activity theory* (Leont’ev, 1978, 1981) – particularly Leont’ev’s “tristratal analysis of joint activity” (Wells, 1999, p. 232) – and *systemic linguistics* (Halliday, 1975).

Of particular importance to the current discussion is the way that Wells refined Leont’ev’s three strata of activity (activity, action, and operation) to apply to the classroom. What necessitated that refinement from Wells’s standpoint was that, “As Leont’ev recognizes, there is nothing [in Leont’ev’s formulation of the three strata] to delimit the scope of the various categories” (Wells, 1999, p. 169). Thus, Wells took it upon himself to delimit the scope of these terms – and to add new terms – in making them amenable to studies of educational activity systems. In doing so, he treated “activity” as the ‘Practice of Education’ or the sum total of all that goes on in a classroom during the course of a school year. [It is important to note that Wells distinguishes between this precise theoretical meaning for “activity” – which, when intended, resulted in the use of quotes around the word – and the non-technical meaning of the term as it is often used in education – which, when intended was indicated by an absence of quotes.]

“Action,” then, represented the various components of curricular enactment, which can fluctuate
in the time span during which they are conducted, from long-term curricular units to short-term curricular activities (with activities here representing the non-technical meaning of the term; p. 250). In order to sub-divide the short-term curricular activities into more manageable segments for analysis, Wells introduced the terms task and step to refer to the sub-actions making up the actions of curricular activity (with steps being combined to perform a task and tasks being combined to complete an “action”).

Appropriation of Wells’s structure to create a video analysis framework for the current study began by treating the instantiations of the MSP lesson structure – whether they lasted a single period or two periods – as representative of Wells’s short-term curricular activities and therefore the “action” level in his system. Continuing this appropriation required finding counterparts for the task and step levels of Wells’s system.

In order to establish the task and step equivalents in the MSP enactments, it was necessary to create a procedure for marking the boundaries between these two different levels of sub-actions; the procedure developed drew on the work of Kelly, Brown, and Crawford (2000). In their discussion of the analysis they conducted on videotape records from a third-grade classroom, Kelly et al. identified two units they employed to segment the video based on the activity of the participants. The larger of the two is the phase unit which they indicate “represents concerted and coordinated action among participants, reflects a common focus of the group, and can be identified by the content of the actors’ talk” (p. 631). They also provided some cues for knowing where the boundary between two phases might be located: “phase units are redundantly marked by physical reorientation or by a shift in social arrangements” (p. 631). The smaller of the two they labeled as a sequence unit, which they suggested involve “more precise demarcations as participants structure the conversations and cue each other interactionally” (p. 631).
In order to make use of these suggestions from Kelly et al., it proved helpful to treat their phase unit as parallel to Wells’s task level. As a result of drawing this parallel and of employing the criteria proposed by Kelly et al. of marking the larger segments by changes in physical orientation or social arrangement, it was found that there were a set of ‘major events’ which recurred in all of the MSP samples. The six task segments common to all fourteen of the lessons were (1) Building Up / Posing the Problem; (2) Generating Solutions; (3) Proposing / Discussing Solutions; (4) Conducting Tests; (5) Analyzing the Test Results; and (6) Formalizing the [‘Correct’] Solution. [Some lessons had an additional task segment such as Sharing Out Prior Knowledge in Sarah’s class and Revising Their Plans in Hannah’s class; additionally, some task segments – particularly (3), (4) and (5) – would occur multiple times within a single lesson.] Transitions between these segments were indicated by changes in the physical and / or cognitive goals of tasks and by discourse cues such as when Sandy said to her period 3 class, “So you need to decide some number of grams of sulfur that will make this reaction work the best. So, what do you think that would be?” which marked the boundary between Building Up / Posing the Problem and Generating solutions.

The final component of the video analysis framework was generated by drawing a parallel between Kelly et al.’s sequence units and Wells’s steps level. [The reason for utilizing Wells’s terminology rather than that of Kelly et al. will become clear in the discussion of the discourse analysis.] Related to the MSP structure, these step segments were seen as the acts of which the major task events were composed. The boundaries between these acts were identified by more subtle changes in the cognitive activity of the lesson, such as when Marty went from connecting the activity to previous and future content, to presenting the problem, to talking about the main tool (the Bohr model) which might be used to solve the problem all within the task
segment of Building Up the Problem. Further, they were distinguished by more subtle changes in the physical activity such as when Nancy (and her student helpers) moved from preparing a test mixture to pouring it onto a surface in a fume hood to putting a magnesium-ribbon fuse into and lighting the magnesium ribbon all in the course of one Conducting a Test segment. Finally, repetitive acts within a task segment – such as the offering and evaluating of different solutions in the Proposing / Discussing Solutions segment – indicated step boundaries.

The issue arose as to how the different parts of a particular task segment – such as the offering and evaluating of solutions – should be treated in terms of whether or not they represent different step segments. It was recognized that such decisions had to be made on a case-by-case basis and required bringing the discourse-analytical process to bear on this issue. The following criteria was established for making these decisions: Different components of a task segment were not treated as separate step segments if the discourse instantiating these acts was part of a single sequence [a term that will be defined in the discourse analysis section] and were treated as separate step segments if the discourse involved was part of temporally-separated sequences.

The marking of the task and step boundaries within a lesson was done by opening the QuickTime® movie file for the lesson in the StudioCode® video analysis software and then placing these boundary markers in a StudioCode® timeline which was linked to the movie file. This produced an automatic time stamp for these markers. For the task boundary markers, a text label was added to identify the nature of the task segment (one of the six main units common to all the lessons or one of the additional ones unique to that lesson). For the step boundary markers, a text comment was added to provide an analytical note concerning what occurred in that sequence unit such as, “Involves group just to right of camera presenting their explanation of the period trend discrepancy (from Marty’s Pd 4 lesson).” A StudioCode® timeline containing a
complete set of task and step markers was produced for all fourteen of the videotaped lessons. (Two sample timelines are found in Appendix F.)

**Solution Pathway Maps**

While the StudioCode® timelines are useful for showing the structure of activity within each lesson, it was decided that another form of representation was needed to show the relationship between the structure of activity and the exploration of ideas within these lessons. The form of representation which was developed has been dubbed Solution Pathway Maps (SPM) and the purpose of this sub-section is to familiarize the reader with the content of those maps. [A sample map – representing the activity and idea exploration in Sarah’s period 5B class – is on the next page; the entire set of maps for all fourteen lessons is found in Appendix G.]

As a starting point for this discussion, the reader needs to understand that these maps were designed to represent three main pieces of information for each lesson: (1) The temporal flow of events; (2) the structure of activity; and (3) the way that different solution proposals were generated, offered, vetted, tested, etc. Additionally, all of that information was to be connected to the discourse that occurred during the lesson.

Explaining the way those three main pieces of information were coordinated in the lesson is most easily done by beginning with the way the structure of activity was represented. Looking at the sample SPM on the next page, the reader will note that there are a series of events in the lesson that flow from one into the other as indicated by various object shapes connected by short line segments. [There is no significance to the fact that some of those line segments go down (such as the one between “Developing List of 5” and “Sharing Out Prior Knowledge”) or have a couple of 90° bends in them (such as the one between “Find Moles of Zn” and “6.54 g.”; this was done for ease of formatting.] Those object shapes represent the different task segments which
Figure 1: Sarah's Period 5B Lesson Solution Pathway Map

- **Posing Problem**
- **Develop List**
- **Sharing Ideas**
- **Generating Solutions**
- **Proposing Solutions**
- **Develop FS5's Idea**
- **Critique idea by FS2 and Sarah**
- **By Logic of Discussion**
- **Formalizing the Solution**

**Key Points**:
- Exothermic Reaction
- One-to-One Mass Ratio
- One-to-One Mole Ratio
- Line 206
- Find Moles of Zn
- FS5 in line 206
- 6.54
- Develop MS 7/FS5's idea
- Lines 206-276 (FS2): 277-306 (Sarah M&MT analogy)
- Vote in S16-318 confirms this (even FS5 does not vote for equal mass idea)
- Sequence 25
- Sequence 27
- Sequence 21
- Sequence 19
- Sequence 18
- Sequence 17
- Sequence 16
- Sequence 15
- Sequence 14
- Sequence 13
- Sequence 12
- Sequence 11
- Sequence 10
- Sequence 9
- Sequence 8
- Sequence 7
- Sequence 6
- Sequence 5
- Sequence 4
- Sequence 3
- Sequence 2
- Sequence 1

**Notes**:
- Line 15: FS5 makes connection to previous day's question
- Poses problem in line 20

**Additional Details**:
- A couple of these sequences were initiated by students
- Sequence 16 indicates improper orienting basis, but it is also where Sarah reformulates goal (line 175)
- Question/Challenge: 101, 102, 103
- Lines 69, 103, 104, 121, 122, 124
- 753
- Lines 59, (molar mass), 99 (direct reflection of mass defect)
- 100 (molar ratio)
- 103, 134 (direct ref. of 100)

**Technical Notes**:
- 13g S
- MS7 in line 204
- 13g
occurred within the lesson. To indicate the different objectives that those task segments accomplished, the following conventions were used: A rectangle was utilized for any section in which work was done on building up the problem, or generating, proposing, evaluating, and revising solutions; a triangle was employed for sections involving the testing of solutions; a circle was used for sections involving the analysis of test results (with the exception being that an octagon was used if that analysis lead to the conclusion that the solution was unsuccessful); and a diamond was utilized in the section where the results of the activity were formalized in terms of the ‘correct’ solution and its explanation. To add further clarity, a verbal identification of the segment’s function is given inside the object.

With that information in place, it is now possible to describe how the temporal flow and connection to the discourse was brought into the maps. Reading across the map from left to right is equivalent to moving through the events of the lesson from the beginning of the activity to the end. To provide more specificity, a time interval has been placed above each task segment object to represent the time period (from the video) during which that segment occurred. For instance, the Generating Solutions task segment took place between 10:40 and 13:01 in Sarah’s period 5B lesson. Additionally, the connection of the task segments to the discourse has been made by placing sequence intervals above each task segment object to represent the discourse sequences (again, this term will be defined later) which transpired during that segment. As an example, discourse sequences 16 and 17 happened during the Generating Solutions segment in Sarah’s period 5B lesson.

The third component of the maps to be addressed is the way that the exploration of ideas was depicted in these diagrams. The only ideas which were given representation are those related to trying to solve the main problem(s) of the activity. If that idea corresponded to an
actual proposal for a solution to the problem, it was symbolized by a pentagon. A further
distinction was made between proposals made by students, which were represented by a regular
pentagon, and proposals made by teachers, which were represented by an inverted pentagon.
[There were no such proposals made by Sarah in the period 5B lesson, but there were in two of
her other lessons.] If that idea represented a thought that contributed to the development of a
solution proposal, it was symbolized by a light bulb. If there was a discussion of any length
(beyond just one or two exchanges) which followed the proposal of an idea and represented
either the further development of that proposal or information offered in support of it, a regular
trapezoid was used to depict this; if the discussion involved information designed to criticize or
refute the proposal, an inverted trapezoid was used. For instance, in Sarah’s period 5B SPM,
there is an inverted trapezoid indicating a discussion initiated by FS 2 which indicated a flaw in
the logic of the ‘13-gram’ proposal (made by FS 5).

The fourth component of the maps to describe is the way that the exploration of the ideas
/ proposals within a lesson was connected to the structure of activity and discourse of the lesson.
Solid lines or lines with arrows were used to show how the examination of ideas was tied to the
action of the task segments. For example, one can see how both the ‘13-gram’ proposal and the
‘6.412-gram’ proposal have such lines linking them to both Conducting Test and Analyzing Test
task segments in Sarah’s 5B lesson. Additionally, dashed lines with arrows at the ends were
utilized to represent cases where the discourse indicated associations being made between one
idea / proposal and another (such as when one group would use another group’s idea to modify
their proposal) or involved explanations that related back to a previously-suggested proposal.

One of the most important symbols tied to the exploration of ideas is the octagon. This
represents the dead end for that idea: when it was discarded or recognized as untenable. A
significant feature of this representation was that an attempt was made to distinguish between when the dead end resulted from an empirical test of an idea versus when it resulted from a logical analysis of that idea: This distinction is presented in the form of a verbal description found within the octagon. For example, FS 5’s ‘13-gram’ proposal had already been identified as a dead end through criticisms presented by FS 2 and Sarah well before the empirical test of this solution took place (although the test further confirmed this fact).

The final feature of the SPMs to identify is the use of dashed shapes, which are indicative of events around which there is some element of uncertainty. This was used, for instance, in cases where the validity of an empirical test was in question (symbolized by dashed triangles), which often lead to the test being repeated. It was also used in cases where there was some ambiguity concerning whether a solution had definitely been shown to be untenable or not (symbolized by dashed octagons).

All of the features of the SPMs just discussed have been summarized in a table that is found at the beginning of Appendix G prior to the presentation of any of the actual SPMs.

**Discourse Analysis**

**Unit of Analysis**

The main goal of this study is to characterize the interactions in the sample MSP lessons; while these interactions can take myriad forms, the one most likely to dominate in the classroom is spoken discourse (Cazden, 2001). The first problem encountered in this area of the analysis was deciding what size pieces that discourse should be ‘chopped into’ in order to maximize the amount of information concerning the interactions which may be gathered from it.

There have been numerous proposals as to how to segment discourse for such an analysis and these proposals have varied in the length of the discourse segments they favor (Taboada &
Zabala, 2008). On the one end of the spectrum are segments like Chafe’s (1994) *intonation unit*, which represents “a small amount of information which, it is plausible to suppose, is that part of the speaker’s model of reality on which his or her consciousness is focused at that moment” (p. 29) and “is typically expressed with four words of English” (p. 65). Also in this size range are the *message units* used by Kelly and Crawford (1997), which “are the smallest unit of linguistic meaning and must be identified *post hoc* by cues to contextualization including intonation, pitch, tempo, pause structure, proxemics, kinesics, and tempo (Gumperz, 1992)” (p. 540). At the other end of the spectrum is Grosz and Sidner’s (1986) *discourse segments*, which represent a sequence of utterances that the hearer recognizes as being topically related (p. 177), the boundaries of which can be identified by *cue phrases* such as “in the first place” (pp. 177 – 178).

Given the goal of the study reviewed above, it was necessary to find a way to ‘zoom in and out’ between smaller units of discourse and larger segments. This indicates that relying on a single discourse analytical unit will likely be insufficient for the current work and that what is really required is a *system of related units*. Further, the way in which those units are related must be clearly specified so that the means for analyzing and describing the movement back and forth between them may be made readily accessible.

Such a system of units was found, once again, in the work of Wells (1999). In Wells’s system, the smallest unit of analysis is the *move* (p. 236). For Wells moves represent the basic components in the exchange of information between interlocutors and he categorizes moves in terms of what part of that exchange process they accomplish: *initiation* (I), *response* (R), or *follow-up* (F) (p. 337). Moves are identified at the level of a speaker’s *turn*, with each turn being labeled either I, R, or F, the exception being that certain turns are coded as *backchannel* which Wells – borrowing from Coulthard (1977) – defines as “the term for a contribution made by a
listener in the course of a speaker’s turn in order to signal that he or she is following the speaker’s drift” and which Wells indicates “do[es] not constitute moves in the sense intended here” (Wells, 1999, p. 266). Further, a single turn can be identified as representing more than one move – usually, a related pair such as I and R or R and F. (Some examples in the next subsection will make it clear how this could be the case.)

In Wells’s system, the next unit up in size is the exchange (p. 236), which is composed of a combination of two or more moves, and, therefore, two or more speaker turns (of course, the content of those turns need not just be verbal, although this is what Wells focused on). As was discussed in the Literature Review, Wells and Nassaji (2000) built off of the work of Berry (1981) to categorize exchanges in spoken discourse into two types. The first type is a nuclear exchange, “which can stand alone, independently contributing new content to the discourse” (Wells, 1999, p. 236) and which consists minimally of an initiation and a response move, but may also include a follow-up move. The second type is a bound exchange, which somehow contributes to, extends or elaborates a nuclear exchange and therefore “depend(s) on the nuclear exchange in some way” (p. 236). As was also noted in the Literature Review, Wells and Nassaji (2000) identified three sub-types of bound exchanges: preparatory, embedded, and dependent (p. 378). Given that, within the dependent sub-type, “some aspect of the nuclear exchange is developed through further specification, exemplification, justification” (p. 236), identifying and dissecting examples of this sub-type will be an important component of this analytical work.

There is one yet-larger discourse unit in Wells’s system that deserves consideration: the sequence. Wells (1999) indicates that a sequence consists of “a single nuclear exchange and any exchanges that are bound to it” (p. 236) and he clearly places a premium on examining this unit of discourse because “it is in the succession of moves that occurs in following through on the
expectations set up in the initiating move in a nuclear exchange that the “commodity” being exchanged . . . is introduced, negotiated and brought to completion” (p. 236). The boundary of sequences is determined by a shift from the topic upon which the nuclear exchange is focused.

There are three things of value to be gained by considering the sequence level of discourse. The first is that it helps to complete the picture of the relationship between interactions – through discourse – and the structure of activity. Wells (1999) presents a diagram that shows the Sequential Organization of Spoken Discourse in his system (p. 237). It specifies that moves (the “smallest building block”) are combined to form exchanges – both nuclear and bound; that exchanges are put together to produce sequences; and that sequences are strung together to create an episode (“all the talk that occurs in the performance of an activity”; p. 237). What this suggests is that the episodes will be equivalent to the task (and sometimes – depending on their length – the step) segments and thus the way that sequences are constructed and connected in these segments will be indicative of the relationship between the interactions and structure of activity in the MSP lessons.

The second value of giving consideration to the sequences is that they can serve as a means for determining whether parts of a task – such as offering and evaluating solutions in the proposal task – should be marked as one step or multiple steps (a point made previously). If those parts of a task are portions of the same sequence, then it does not seem logical to treat them as separate steps; however, if those parts are located within different sequences, then it seems quite reasonable to mark them as separate steps. [Hopefully it is clear now why Kelly et al.’s terminology of phase and sequence could not be used: because it would have caused confusion related to the use of Wells’s term sequence.]

The final value of considering the sequence units is that their length may serve as an
indicator of the extent to which participants’ ideas are fully explored and developed. Given the principles underlying the notion of progressive discourse – particularly the openness commitment – a lesson full of highly abbreviated sequence units may indicate that ideas were not exposed to the kind of critical analysis necessary to encourage the development of scientific thinking skills in the participants. On the other hand, longer sequence units, particularly if they are rich in follow-up moves, may show proper attention has been given to progressive discourse.

To summarize, then, what has been presented in this sub-section: The smallest unit of analysis will be the move and each speaker’s turn will be coded according to the type of move(s) exhibited within it – initiation, response, follow-up. Further, the specific functions of those moves in relation to the activity within the MSP lessons will be evaluated (this idea will be developed in the next sub-section). The determination of those specific functions will necessitate widening the analysis unit to include a careful examination of the way those moves are built into exchanges; ‘zooming out’ in this way will also make it possible to better understand the interaction-activity structure relationship. Finally, in order to gain insight into the manner in which participants’ ideas are developed – particularly in relation to the principles of progressive discourse – it will be necessary to widen the unit an additional level to consider the content of sequences. How this analysis will be conducted and how the coding of the categories within these different levels of analytical units will be done is the subject of the next sub-section.

Transcription Format

As was noted previously, all fourteen sample MSP lessons were fully transcribed; nine of these transcriptions were completed by the researcher and the other five were completed by a science education master’s student (who became the co-coder) working on a related project for his thesis. The researcher went through all five of the transcriptions produced by the master’s
student to check for mistakes, and the master’s student similarly reviewed three of the researcher’s transcriptions. The final, checked transcriptions were stored as Word documents.

Within the transcription, the discourse was broken down into sections that corresponded to the task segments of the lesson (e.g. “A. Building up the Problem and Prior Knowledge” from the beginning of Sarah’s period 3 lesson). Within those sections, the discourse was presented as numbered entries that corresponded to speaker’s turns, with the numbers running consecutively from the beginning to the end of the transcript. [Exceptions to each entry representing a whole turn for a speaker occurred when a single turn was determined to include a task, step, or sequence boundary, in which case the turn was split into two entries – one representing the discourse leading up to the boundary and one the discourse coming after the boundary; an illustration of this will be presented in the next sub-section.] Further, student speakers were simply identified by a label such as FS 3 to indicate a female student who was the third student to speak in that lesson. An example of these conventions from Nancy’s period 3 lesson follows:

21. Nancy: How would I know?
22. FS 3: Is ‘Ag’ plus three?
23. Nancy: Okay, figure it out for me.
24. FS 1: Let me check it out for you.

There was a minimum amount of notation added to the transcription to indicate features of how the discourse was spoken. The only notations used were ellipses (…) to indicate a noticeable pause in a speaker’s talk (sometimes, if the pause was particularly long, a time length would be included and placed in brackets prior to the next segment of speech); italics to represent emphasis on a word or phrase to bring attention to it; and left carrots (<) to indicate overlapping speech as exemplified in the following excerpt from Sarah’s period 5B class:

218. Sarah: Um, one mole of sulfur? You’re suggesting one mole of sulfur too? [No apparent response] We have <‘.2 moles’ . . .
219. Same male student as line 217: <Oh, no, wait – we need ‘.2’ moles of <<sulfur.
220. FS 5: <<Wait, doesn’t that have to be even on both <<<sides?
221. FS 6: <<<So you would have to convert moles to grams.
222. FS 5: Doesn’t that have to be even <<<on both sides?
223. Sarah [towards FS 6]: <<<Okay. [Towards FS 5 ‘Does it have to be even on both sides?’ – what do you me- . . .?

In this excerpt, Sarah’s statement of “‘.2 moles’” is overlapped by the male student’s utterance “Oh, no, wait . . .” and thus a single left carrot (<) is placed at the beginning of the overlapped talk from each of those speakers. Next, “sulfur” at the end of the male student’s statement is overlapped by the beginning of FS 5’s “Wait, doesn’t that . . .”; to distinguish this overlap from the previous one, two left carrots (<<) are employed. One can then follow the addition of one left carrot throughout the remainder of this excerpt as each new overlap occurs to clearly identify which two speakers were producing the overlap.

Data to Be Included in Discourse Analysis

It was upon this minimally-annotated transcription of the classroom talk that the discourse analysis was conducted. Sections of the transcription from a lesson were transferred into a coding document for that lesson set up to allow the codes for exchange, move, and function type to be applied (see below for examples of this coding process). An important discussion point is how the determination was made as to which sections to place in the coding document and which samples to exclude from it.

The Building Up the Problem task segment was the place in which the teacher framed the activity for the students and posed the problem to them; it was also the place for reviewing previously-discussed material that either helped create a context for the activity or could be useful in solving the problem. As such the discourse in this segment in each of the lessons was analyzed at a more macro level with regards to what components were included in the framing
discussion and how the problem was set up for the students. The discourse for these segments was universally excluded from the coding documents because the talk here was largely monologic (Mortimer and Scott, 2003) and when it was dialogic, it involved exchanges related to the reviewing of previous course content, such as when Sandy asked her students in period 3 whether zinc sulfide is an “ionic, molecular, or acidic” compound and MS 1 responded that it is “ionic.” Thus, there was no exploration of ideas in these segments and no opportunity for the researcher to examine the way in which the interactions might have connected to the principles of progressive discourse.

Similarly, the Formalizing the Solution segment was the place in which the teacher brought closure to the activity by working towards the accepted scientific explanation that could account for the ‘correct’ solution to the problem. For the purposes of this research, it was again important to examine the discourse in this segment of each lesson at a macro level, with a particular focus on the extent to which the scientific explanation was connected to both the tenable and untenable solutions explored and the relationship between the language used in the students’ discussions of their ideas and that used by the teacher in presenting the accepted scientific explanation. Much like the Building Up the Problem segment, the discourse in this segment tended to be monologic, and when it was dialogic, tended to be focused on recapping the events of the problem-solving activity. Therefore, these segments were universally excluded from the more micro level discourse analysis.

The content of the four segments in between -- Generating Solutions; Proposing / Discussing Solutions; Conducting a Test; Analyzing the Test Results – were included in the more micro level discourse analysis because this is where the exploration of ideas took place and the key interactions related to implementing (or failing to implement) the commitments of
progressive discourse were salient. The one exception to this is that the Conducting a Test segment(s) or portions of it were excluded when the discourse centered around procedural details such as picking students to prepare samples for testing, questions about how to weigh samples properly, or discussion by the teacher of the material being used to ignite the test samples. To insure that portions of this segment containing significant interactions related to the exploration of ideas or to issues related to the empirical testability commitment were not inappropriately removed from more detailed analysis, the researcher and co-coder went through these sections together and discussed whether each portion should be included in or excluded from discourse coding until full agreement was reached.

The segments which were not universal to all lessons – such as the Sharing Out Prior Knowledge segment found in each of Sarah’s lessons and the Revising Plans segments present in each of Hannah’s lessons – also tended to play some role in the exploration of ideas related to solving the problem and tended to be rich in interactions related to the principles of progressive discourse. Therefore, these segments were included in the discourse analysis process.

The final point to be made regarding which data was subjected to the detailed discourse analysis is that all segments or portions of segments from each of the fourteen lessons which fit the list just presented for inclusion into this process were analyzed. Examining all of the appropriate discourse from each of the lessons conducted by a particular teacher allowed a more thorough description of the way that each teacher brought the MSP structure into being in her / his classroom to be constructed. However, as was noted earlier, in the case where numerical comparisons between teachers were made (e.g. looking at the frequency of certain discourse moves), only the data obtained from the first two lessons for each teacher were compared.

*The Discourse Analysis Procedure*
Marking Sequences

The first step in the process was to segment the talk in the sections being analyzed into sequences. The boundaries for sequences were identified based on the principle that a sequence should capture all of the action around the exploration of a single idea/topic – and thus all of the discourse exchanges related to the request for proposal, proposal, requests for elaboration, elaboration, etc. of that idea/topic. How that principle can be applied to the analysis of classroom discourse will be illustrated through its application to two excerpts – one from Wells’s (1999) corpus and one from the researcher’s data. The reason for including Wells’s excerpt is that he left the principle just presented implicit in the discussion of his system, so it provides an exemplar to which the researcher’s excerpt may be compared to consider the validity of the inference used to construct that principle.

Wells’s excerpt is taken from an elementary classroom (grade 4/5) during a lesson at the beginning of a unit on weather (p. 253). In this section of transcript, the teacher is trying to elicit proposals from students regarding the kinds of activities in which the class might engage to learn about the weather. [In the transcript, “T” stands for teacher and “L” and “S” identify two students]. The excerpt is taken from p. 254 of Wells (1999):

Sequence 2*

10. T: Another idea? [Several hands up, including Lyndsey’s]
11. T: Lyndsey?
12. L: Maybe you could have some games (inaudible)
13. T: OK. Maybe some people would like to make up some games about the weather that would allow you to learn. Uhhuh.

Sequence 3*

14. T: Other ideas about how we can go about this?
15. S: We can like look in newspapers and stuff –
16. T: OK
17. S: -- see if we can find articles or something like magazines or something
18. T: Great. So I’d like you to start looking in the newspaper and when you find articles about weather you could cut them out and bring them in . . .

[* indicates that these were the sequence labels proposed by Wells himself]

In this excerpt the first sequence includes the teacher’s request for proposals, Lindsey’s proposal and the teacher’s evaluation of that proposal. Within the same turn in which the teacher evaluates Lindsey’s proposal (and engages in the kind of uptake of which Nystrand and Gamoran (1990) spoke), the teacher begins a new sequence by making another call for proposals – thus the reason that the turn was split into two different numbered entries. The second sequence includes a new proposal by student “S” and the discussion around that proposal.

The researcher’s excerpt is taken from Sarah’s period 1 chemistry class. Prior to this excerpt, Sarah had presented the problem to the students (‘Determine the amount of sulfur that must be combined with 13 grams of zinc to produce the most effective reaction’) and she has asked them to generate and propose ideas from their previous experiences in this class which might be relevant to solving the problem. The notations employed for identification of participants are those that were discussed previously:

Sequence 4*

6. Sarah: Okay, I’m just going to call on some people and I’m going to write some stuff down up here [points to transparency]. Um, let’s see. [MS 3]**, what’s one thing?
7. MS 3: ‘Redox’.
8. Sarah: Okay, it is a ‘redox reaction’. [Writes this on transparency.] How do we know it’s a redox reaction? [MS 4].
9. MS 4: ‘Synthesis reaction’.
10. Sarah: It’s a ‘synthesis reaction’. That’s a huge hint. Um, what else – how else could we figure out it’s . . . Yeah [directed to FS 5] . . .
11. FS 5: Zinc is oxidized and sulfur is reduced.
13. FS 1: How do you figure that out again?
14. Sarah: . . . ‘Sulfur reduced’ [writes on transparency]. Uh, okay, we can go over that quickly [referring to FS 1’s question]. Um, any element by itself is what oxidation state?
15. A couple of students: ‘0’.
17. Unknown male student: ‘—2’
18. FS 1: Oh, ‘+2’.
19. Sarah: ‘+2’. This one [sulfur] is ‘—2’. So zinc goes from ‘0’ to ‘+2’ – that means it loses electrons. And sulfur goes from ‘0’ to ‘—2’; it gains.
20. Sarah: Okay, good. That also told us (inaudible) that it’s a synthesis reaction [writes this on transparency].

*Sequence 5*

21. Sarah [after a couple of second pause] Um, [MS 6], what’s one thing that you had?
22. MS 6: Uh, there’s one atom of each.
23. Sarah: One atom of each . . . in the reaction?
24. MS 6: Yeah.
25. Sarah: Okay, how did you figure that out?
26. MS 6: (Inaudible)
27. Sarah [7:07]: So there’s a ‘1’ understood to be here [pointing to position in front of ‘Zn’].
28. MS 6: Yeah.
29. Sarah: Okay. [Writes a coefficient of ‘1’ in front of each species.] What do we call these things?
30. A couple of students: Coefficients.

[*The sequence numbers represent the position of these sequences in the larger transcript. **Designations such as [MS 3] indicate that a speaker – usually the teacher – is naming another participant in the classroom]
In essence the same pattern found in Wells’s excerpt can be seen in the researcher’s excerpt, although the sequences are longer because there is more discussion around each idea. In the first sequence, MS 3 responds to Sarah’s request for proposals by suggesting that knowing the reaction belongs to the ‘redox’ type may be useful information for solving the problem. Sarah asks for an elaboration of this proposal by asking how one knows that it is a redox (oxidation-reduction) reaction and MS 4 responds with ‘Synthesis reaction’. While that may seem to be an unrelated fact, the students had learned previously that all synthesis reactions were also redox reactions, so this is relevant information. The exchanges around the idea of ‘redox reaction’ continue with a discussion of how one identifies what is oxidized and reduced in the reaction and concludes with Sarah making an evaluation of that discussion and identifying the other key idea that came out of it (that this is also a synthesis reaction; line 20). A new sequence is then indicated by Sarah making a second request for proposals and the entire content of that sequence centers around the idea behind that proposal – the notion of ‘coefficients.’

**Coding Exchanges**

The last two examples indicate that single sequences can vary greatly in length depending on how much effort is exerted by participants in exploring an idea. They also show that the principle discussed above can be useful in identifying sequence boundaries. The analytical objective of marking such boundaries can be further enhanced by completion of the second and third steps in the analysis: identifying the nuclear and bound exchanges in the sequence and the type of move(s) performed in each turn. [These two steps are completed simultaneously because of the close relationship between the kind of exchange occurring and the moves available at different points within each type of exchange.]

In Wells’s system nuclear exchanges are simply labeled as such; however, bound
exchanges are specifically coded as to the sub-type they represent: *preparatory* (Prep.), *embedded* (Emb.), and *dependent* (Dep.). For Wells preparatory exchanges are those discourse pairs that set the stage for a nuclear exchange, “such as the bid-nomination sequence in whole-class question-and-answer sessions” (Wells, 1999, p. 236); these are thus likely to occur *before* a nuclear (or dependent) exchange. The researcher found it valuable to expand this category to include another kind of exchange which can precede nuclear exchanges – one in which the acquisition of background information necessary to engage in the nuclear exchange occurs. An example of this kind of preparatory exchange can be found in the following excerpt from Marty’s period 6 chemistry class:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exchange Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>155. Marty: So, right here, this group [gesturing to back middle lab group] . . . which period do you have?</td>
<td>Prep.</td>
</tr>
<tr>
<td>157. Marty: You have lithium, beryllium, and – all the way across there.</td>
<td>Prep.</td>
</tr>
<tr>
<td>158. MS 10: Uh, they’re all <em>the same</em> [in their radius].</td>
<td>Nuc.</td>
</tr>
<tr>
<td>159. Marty: This group said that each element – lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, neon – are all the same.</td>
<td>Nuc.</td>
</tr>
</tbody>
</table>

The goal of the action in this part of the lesson was for each group to predict the trend in the pattern of atomic radii across a period of elements which that group was assigned. Because this was the goal, the nuclear exchange central to this sequence does not begin until line 158 in which Marty conducts an initiating move to get the group to present their prediction of the trend for their period. Thus the information gathered through the three-part exchange in lines 155 – 157 can be seen as preparing for the nuclear exchange by having a member of the group [MS 10] indicate the period for which that group was responsible.
For Wells embedded exchanges are a response to “problems in the uptake of a move in the current exchange” (p. 236) and thus usually involve what Schegloff, Jefferson, and Sacks (1977) identify as repair strategies; these, then are often seen in the middle of a nuclear (or dependent) exchange. An example of this kind of embedded exchange can be found in the following excerpt from Sarah’s period 7 chemistry class:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exchange Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>[4 seconds pause] What do you think [MS 1] – you wrote them down?</td>
<td></td>
</tr>
<tr>
<td>88. MS 1: What was the question?</td>
<td>Emb.</td>
</tr>
<tr>
<td>89. Sarah: Do you think these two things here are going to be helpful in determining how much sulfur to use?</td>
<td>Emb.</td>
</tr>
<tr>
<td>90. MS 1: &lt;Yes!</td>
<td>Nuc.</td>
</tr>
</tbody>
</table>

In this segment of the lesson, Sarah is asking students to evaluate the ideas that have been offered in the previous segment in terms of their utility in solving the problem at hand. This excerpt begins with Sarah making such a request for an evaluation. MS 1 is either not paying attention or did not hear Sarah and, as a result, makes a request that she repeat the question in line 88 – the first move in an embedded exchange pair. Sarah’s response of repeating the question represents the second move in that exchange. MS 1’s utterance in line 90, then, represents the continuation of the nuclear exchange initiated in line 87 now that the conversation has been repaired by the embedded exchange.

Again, the researcher found it valuable to expand the content of the discourse that was coded in this category – in this case, to include exchanges that represented brief ‘asides’ to the main topic of conversation in a particular sequence. An example of this kind of embedded exchange is present in the following excerpt from Marty’s period 4 chemistry class:
In this segment of the lesson, students are sharing out their predictions about what the trend will be in the atomic radius as one moves down a group of elements. Prior to this excerpt, MS 3 has presented his group’s prediction related to this trend (the nuclear exchange in this sequence). As this excerpt begins, Marty is requesting a justification for the prediction and MS 3 provides that justification (lines 99 and 100). Recognizing the theatricality that MS 3 employed in offering his justification, Marty engages in an embedded exchange that represents an aside in lines 101 and 102, before finishing up the dependent exchange with a follow-up move in 103.

In Wells’s system, dependent exchanges really involve an extension of the content of the nuclear exchange by elaborations, justifications, and further queries, and therefore are found after the nuclear exchange (p. 236). Wells’s description of the content of this exchange category proved to be adequate to code all instances that represented dependent exchanges in the corpus of data analyzed.

The researcher found it constructive to employ a fourth category of bound exchange which was not part of Wells’s system: attempted (Att.) exchange. These are cases where a
speaker makes an utterance intended to contribute to the conversation, but that utterance is
(1) aborted by the speaker before it is completed and its full intent can be understood, or (2)
interrupted by another speaker before it is completed and its full intent can be understood, or
(3) that utterance is not taken up as part of the current exchange. An example of this type of
exchange is to be found in the following excerpt from Nancy’s period 6 chemistry class:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exchange Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>188. Unknown female student: That’s too low.</td>
<td>Att.</td>
</tr>
<tr>
<td>190. FS 14: Because it’s the atomic mass divided by ten.</td>
<td>Dep.</td>
</tr>
</tbody>
</table>

This excerpt was located in a segment where students were making new proposals after a
previous proposal had been shown to be untenable. In the nuclear exchange in this sequence
(lines 183, 184, and 187) Nancy asks for a new proposal, gets one from FS 14 and then repeats
this proposal. Before Nancy is able to begin the dependent exchange in which she will ask FS 14
to justify this proposal, an unknown female student questions the proposal – an evaluation which
is not taken up in this sequence and which never gets re-entered into the conversation in this
lesson. Instead, Nancy proceeds with her request for justification in line 189.

Coding Moves
As noted previously Wells suggested that there were three categories of moves that could take place in any of the types or sub-types of exchange: *initiation* (I), *response* (R), and *follow-up* (F) (although, as will be discussed below, each move within a particular category could function in a number of different ways). Putting the information from the last couple of pages together: in Wells’s system, each speaker turn received a code for a type of exchange (Nuc., Prep., Emb., Dep., Att.) and a category of move (I, R, F) – with the possibility of each turn being coded for more than one type of exchange and more than one type of move.

Another example taken from Sarah’s period 3 class should make this exchange-move coding system more clear. It occurs at a similar point in the lesson to the excerpt from period 1 provided several pages back – after Sarah has presented the problem to the students and asked them to determine what parts of their prior chemistry knowledge may be relevant to solving it:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exchange-Move Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>67. Sarah: Um . . . anything else?</td>
<td>Nuc. – I</td>
</tr>
<tr>
<td>[MS 10], what do you got?</td>
<td>Prep. – I</td>
</tr>
<tr>
<td>68. MS 10: I had that the equation has to be balanced because . . .</td>
<td>Prep. – R</td>
</tr>
<tr>
<td>69. Sarah: Okay. ‘Equation has to balance’.</td>
<td>Nuc. – R</td>
</tr>
<tr>
<td>[Writes on transparency] Is it balanced right now?</td>
<td>Nuc. – F</td>
</tr>
<tr>
<td>70. MS 10: Yes.</td>
<td>Dep. – I</td>
</tr>
<tr>
<td>71. Sarah: When we’re talking about balance an equ-</td>
<td>Dep. – R</td>
</tr>
<tr>
<td>. . . balancing an equation, um, what are we trying to balance?</td>
<td></td>
</tr>
<tr>
<td>72. [Several students make inaudible comments to which Sarah does not respond, then . . .]</td>
<td>Att. – I</td>
</tr>
<tr>
<td>73. Unknown male student: It’s the amount of the atoms.</td>
<td>Dep. – R</td>
</tr>
<tr>
<td>74. Sarah [making abrupt pointing gesture]: Okay, <em>atoms</em>. So then if [FS 5] used ‘one mole of zinc plus one mole of sulfur and one mole of zinc sulfide’, what other interpretation can we make from this coefficient?</td>
<td>Dep. – F</td>
</tr>
</tbody>
</table>
[Short pause] [MS 11], do you know? Prep. – I

75. [No response] Prep. – R

76. Sarah: [MS 12]. Prep. – I

77. MS 12: Can you say Prep. – R

it’s one mole of zinc sulfide?

Dep. – R

78. Sarah: Yeah, we did Dep. – F

. . . we do have that. Emb. – I

79. MS 12: Oh yeah, I thought that’s what you were asking. Emb. – R

80. Sarah: Before we talked about moles, what other Dep. – I

interpretation did we use for the coefficients?

81. [A couple of seconds elapse; Sarah can be seen tapping Emb. – R

her fingers on the side of the overhead.] 82. Unknown female student: Molecules. Dep. – R

83. Sarah: Molecules. Okay. And I’m gonna just, uh, Dep. – F

substitute ‘atoms’ here [below zinc] because zinc

is just by itself. [Reading as she writes on the transparency].

So, ‘one atom of zinc’ reacts with how many atoms of sulfur? Dep. – I

84. Unknown male student: One. Dep. – R

85. Sarah: One. [Writes ‘one atom of sulfur’ on transparency] Dep. – F

There are a couple of points worth considering about the coding work presented above.

The first is with regard to the way in which multiple exchange types / moves become manifested
in a single turn by a participant. In line 69, Sarah’s two statements, “Equation has to be
balanced” and “Is it balanced right now?” can easily be separated and correlated with the two
exchange types (Nuc. / Dep.) and moves (Follow-up / Initiation) accomplished by this turn. In
other instances – such as MS 12’s turn in line 77, it is necessary to break up a single statement
into phrase ‘chunks’ in order to show the way it represents multiple exchange types and moves.

The other point is regarding the embedded exchange that occurs in lines 78 and 79. It
takes place as a result of the fact that MS 12 shows improper uptake of Sarah’s question posed in
line 74 by providing an answer that represented information Sarah had already given as part of
her question. This embedded sequence – along with the lack of response noted in line 75 – indicates that the question was not understood by the students (who otherwise almost always responded immediately to Sarah’s questions) and that MS 12 was looking for any answer possible to get the conversation moving past the awkward silence that had developed.

**Coding Functions**

The final component of the discourse analysis scheme was the *function codes* which were used to identify what each move in the dialogue was intended to or did accomplish. While the function codes are an integral part of Wells’s system, in neither Wells (1999) nor Wells and Arauz (2006) is this component elucidated as a separate entity as is done with the other three components (move, exchange, and sequence). Although it is obvious what a function code represents, it is not so obvious how the function codes were generated in Wells’s system. In Wells (1999) one can discern the influence of Sinclair and Coulthard’s (1975) work on this process, as in the function codes *give relevant example* and *extend previous contribution* (Wells, 1999, p. 248 and p. 338). Further, in Wells and Arauz (2006), these two authors explicitly discuss the impact of the research by Nystrand, Wu, Gamoran, Zeiser, and Long (2003) on the evolution of this system. However, the details of the process involved in developing the function codes are not revealed in either of these publications. Given the influence that the function codes will have on the data used to answer the research question of this study, it is imperative that the route by which they were developed and then applied to the data be made highly transparent.

Recognizing that the codes had the purpose of trying to characterize the interactions which were actually located within the data, it was not appropriate to develop those codes in an a priori manner. Instead, it was necessary to code the discourse through “a close examination of the data” (Brott & Myers, 2002, p. 148) itself, using an open (Strauss & Corbin, 1990) or
emergent coding approach. This endeavor began by going through a document containing the to-be-analyzed data from one of the lessons (Sarah’s period 1 class) with the sequence boundaries in place and the exchange and move codes already inserted. A set of codes – guided by an understanding of the goal of the activity and the theoretical framework being used by the researcher – was generated which accounted for all of the discourse moves in this data. With an initial set of codes in hand, the researcher moved on to a second document (containing the to-be-analyzed data from Sandy’s period 3 class) and went through the content – modifying, adding, and deleting codes as appropriate from the initial set. This procedure was continued – in the manner of a constant comparative analysis (Merriam, 2002, p. 8) – until the researcher had gone through all of the to-be-analyzed data for each of the lessons and developed a set of stable codes that were able to capture the function of each move within the entire corpus of discourse data.

In completing the procedure just described, the researcher was following the philosophy of trying to create a comprehensive coding scheme in the manner laid out by Wells and Arauz (2006; see especially the Appendix on pp. 425 – 428). This resulted in a code set consisting of 75 separate codes in the original list. [This document can be found as Appendix H.] While there was certainly value in creating such a list of codes, it was recognized that coding every turn in the dialogue of each lesson would draw attention away from the goal of this research: understanding how the interactions in each lesson related to the way ideas were explored and how they contributed (or failed to contribute) to implementation of the tenets of progressive discourse.

Based on this desire to focus the analytical attention on discourse moves having some bearing on the movement through the problem space and/or some relationship with the progressive discourse commitments, elements from the original list which seemed to be most strongly associated with these functions were pulled out and organized into a more condensed set
of discourse function codes. This set was revised and refined over several sessions during which the researcher worked with the co-coder on preparing to go back to the data and re-code it. The result of these discussions between the researcher and the co-coder was that the final set of codes was not simply a sub-set of the larger, original set, but was a re-working of that larger set to make it more effective in teasing out the desired information from the discourse.

The final code set appears in the table below. The information in this table is replicated in Appendix I; additionally, though, a ‘definition’ of what each code represents and an example from the data corpus is offered to provide the reader with a deeper understanding of the codes.

Table 4: Function Codes Used in the Turn-Level Discourse Analysis of the MSP Lessons

<table>
<thead>
<tr>
<th>PD Commitment</th>
<th>Function Codes</th>
<th>Code Abbrev. Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutual Understanding</td>
<td>1. Request // Give Clarification / Elaboration</td>
<td>Req. // Give C / E</td>
</tr>
<tr>
<td></td>
<td>2. Request // Give Re-explanation</td>
<td>Req. // Give Re-expl.</td>
</tr>
<tr>
<td>Expansion</td>
<td>3. Request // Give Idea / Proposal</td>
<td>Req. // Give I / P</td>
</tr>
<tr>
<td>Openness</td>
<td>5. Request // Give Justification</td>
<td>Req. // Give Just.</td>
</tr>
<tr>
<td></td>
<td>7. Support // Modify // Refute Idea / Proposal</td>
<td>Sup. // Mod. // Ref. I / P</td>
</tr>
<tr>
<td>Re-Utterance</td>
<td>12. Re-Utterance</td>
<td>RU</td>
</tr>
</tbody>
</table>
Because of its uniqueness within the system, there is a code within that set which needs to be discussed in detail here, in the context of this chapter: that is the re-utterance code that stands as its own category. This code represented a specific interest – shared by the researcher and the co-coder – in the way that participants (particularly teachers) would use partial or whole re-statements of a previous speakers’ utterances as a way to either build better comprehension of the content of those utterances (i.e. support the mutual understanding commitment) or to put that content ‘back into the air’ for further examination (i.e. support the openness commitment). That interest was spurred by familiarity with the work done by O’Connor and Michaels (1993, 1996) on revoicing which was discussed in the Literature Review.

The key point made at the end of that discussion of revoicing was that O’Connor and Michaels focused almost solely on structural details of the conversational turns in labeling discourse events as revoicing. The result of this was that different moves having very different functions could still receive this same label. Conversely, moves that performed similar functions might not all be labeled the same way if they varied in their structural details. Because of this limitation (and because as O’Connor and Michaels define it, revoicing actually involves a three-move exchange), the revoicing construct was replaced by the re-utterance code in this scheme. A re-utterance was defined as the circumstance in which one speaker re-states all or part of a previous speaker’s utterance in a manner which contributes to a deeper understanding of the original utterance or a deeper scrutiny of its content. In other words, a re-utterance isn’t a simple ‘parroting’ of what a prior interlocutor has said (such as when a teacher does this as a means of evaluation) – it has to support genuine progress in the discourse. Additionally, it needs to be pointed out that the re-utterance needs to occur in close temporal proximity – within just a few discourse turns – of the previous speaker’s statement or the move would be acting as an
inter textual reference (Bloome and Egan-Robertson, 1993).

With the function codes delineated, it will be useful to end this sub-section with an illustration of these codes ‘in action’ and a discussion of how the codes were determined within this sample. Before presenting the sample, it is important for the reader to know that the coding process enlisted four pieces of information to generate the codes: (1) the goal of the action comprising the task or step segment in which the discourse move was found; (2) patterns within discourse sequences; (3) the nature of the utterances immediately preceding and following the one being coded; and (4) pieces of language (discourse markers, Schiffrin, 1987) which signaled a certain act was being performed by a particular utterance. Sometimes, one of those pieces of information alone was sufficient to generate the code for a discourse move, while at other times it was necessary to use two or more pieces in conjunction to make these determinations.

To see these principles put into action, consider the function codes established in the following trio of sequences which all took place during one of the Conducting a Test segments in Hannah’s period 1 class. [The reader will notice that a sequence is skipped in between each of the sequences presented; in those in-between sequences, Hannah was engaged with the group preparing their sample for testing in procedural details related to that preparation.] As the reader examines these excerpts, keep in mind that Hannah employed various discourse moves to keep other students intellectually engaged while their classmates were involved in getting a mixture ready for testing, an objective which will be clear in the content of these sequences:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exchange</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What do you think [FS 18]?</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Um, I don’t know – I think it might burn longer.</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>
This set of excerpts starts off with a coding challenge: Hannah’s utterance, “What do you think [FS 18]?” (line 133) is ambiguous as to its purpose and could be representative of several different functions. Knowing that it was found within a Conducting a Test segment limited the possibilities, because Hannah never, for instance, made a Request for Idea / Proposal in these segments of the lesson. However, the key piece of information in determining this code is FS 18’s response in line 134. This response clearly represents a prediction related to what FS 18 thinks the sample will do when it is tested. Since FS 18 treats Hannah’s utterance as a request for prediction, and since there is no repair move in line 135 to indicate Hannah was dissatisfied
with this treatment, then Req. Pred. is the appropriate code for Hannah’s nuclear initiation step.

The set of events just described should be compared to what happens in the first two lines of sequence 59. Hannah begins (line 141) with nearly the exact same utterance as in line 133. However, FS 6’s reply speaks to the validity of the proposal which is currently in the testing stage, not to what she expects will happen when that proposal is tested. Because FS 6’s utterance in line 142 represents a refutation of the idea behind the current proposal (using ‘15 grams’ of sulfur in the test mixture), then it is apparent that she treated Hannah’s nuclear initiation not as a request for prediction – like FS 18 did in the previous sequence – but as a request for evaluation (of the idea) and so Hannah’s question in line 141 is coded accordingly. The reader will notice that Hannah follows up the nuclear exchange with a dependent exchange where she does make a request for prediction and receives a prediction from FS 6.

Finally, in sequence 61, Hannah once again uses the ambiguous initiation, “What do you think?”, which is treated by MS 11 in the same manner as it was treated by FS 18 in sequence 57, thus suggesting the request for prediction code. Following that Hannah makes an intertextual reference (“Sticking to the gun- . . . gunpowder theory?”) to a rationale that MS 11 had used in supporting his own group’s proposal earlier in the lesson (that since there is less sulfur than the other ingredients in gunpowder, the same should be true in model rocket fuel) to see if this is his reason for giving a less-than-favorable prediction for the proposal currently in the testing stage. Thus, Hannah is using this reference as a request for justification and therefore MS 11’s simple response of “Yes” actually represents a give justification move.

The description given is sufficient for the reader to understand the crux of the logic that drove the discourse analysis process. One final point needs to be made, though, before leaving this set of excerpts. The function codes found in them were clearly distinguished by some being
typed in bold letters and others being typed in regular font. This was done to replicate the coding format used by the researcher and co-coder, with the codes in bold being those that correspond to the set in Table 4 – the ones that were the main focus of the analysis – and those in regular font being ‘remnants’ from the original set of codes. Both the researcher and co-coder felt that it was useful to employ codes beyond the set in Table 4 in order to keep better track of the flow of the action in the discourse being analyzed. However, the follow-up analysis of the coded data – particularly with respect to determining the frequency of certain discourse moves – will be reserved for the elements captured in Table 4.

Before moving onto the last sub-section of this chapter, the reader may be interested in examining a complete discourse coding document – in this case, the one for Sandy’s period 3 lesson (chosen because it was one of the shortest documents). This document (Appendix J) will give the reader a more complete picture of the process described over the preceding pages.

**Inter-Rater Reliability**

Given the extent to which answering the research question would be reliant on the data obtained from the coding and analysis of the discourse data, it was necessary to obtain inter-rater reliability values (Marshall & Rossman, 2006; Silverman, 2004) for the codes established. For that purpose, a co-coder was enlisted with the following background: (1) He was a student in a science teaching methods course taught by the researcher; (2) he eventually became a member of the ICISS research group (and was funded in this work with money from a grant obtained by the lead researcher in the ICISS group, Dr. Scott McDonald); (3) he has a B.S. in chemistry, an M.S. in science education, and worked 6 years as a research chemist; and (4) he had worked with a portion of the data being used in this study in completing his master’s project. (In that work, the co-coder focused on comparing the content of teachers’ revoicing utterances to the content of
students’ utterances, not on the function of the revoicing in the discourse as in this study.)

The researcher and co-coder engaged in nine training sessions over a three-week period with each session lasting one-and-a-half to two hours. The first training session was devoted to familiarizing the co-coder with the larger discourse analysis framework being utilized by the researcher. The next three sessions were concerned with constructing a set of codes from the original list of 75 which would capture the commitments of progressive discourse as enacted in the classroom talk. This involved discussion over what the minimum set of codes needed to accomplish this objective would be, what names would effectively represent those codes (as this clearly affected when it seemed appropriate to apply them), and the criteria for employing those codes. Once that work had been completed, the remaining five sessions were used to go through samples of data to practice utilization of the coding scheme. In the sessions the researcher and co-coder initially worked through excerpts which were more easily coded because of repeating patterns in the discourse and then moved on to those which were more complicated due to less structured discourse patterns.

Once the training sessions were finished, a sample of data was selected for the purpose of deriving the inter-rater reliability data. As noted by Fan and Chen (1999), typical practice in educational research is to use 10 – 15% of the total data corpus in making such determinations (p. 5), and so this was the target for the amount of data to be used in this analysis for the current study. However, another factor in the selection of the data was that it seemed more valid to run the analysis on entire segments of the data rather than just a certain number of sequences, and to chose segments which would represent a fair sampling of the set found both throughout the series of lessons and within the lessons of a single teacher. Thus, a random selection process was employed in which all of the segments for a particular lesson were numbered, then a die was
rolled, with the number that came up corresponding to the segment from that lesson which would be analyzed. If that segment did not contain at least 10% of the moves to be analyzed within the lesson, then the die was rolled again to give an additional segment. If that segment corresponded to one that had been already chosen for that particular teacher, then the die was rolled again until the number for a segment which was not yet represented came up. This process resulted in the selection of the segments that appear in the tables on the succeeding two pages.

Following the completion of the selection process, the researcher electronically provided a blank set of coding documents for the co-coder to analyze. They contained the entire set of discourse data meeting the criteria discussed previously for each lesson, with the ones that had been selected for gauging inter-rater reliability highlighted. In these documents, the exchange and move type codes were already present because (1) this data was not going to be used for answering the research question (and so did not need reliability determinations to be made upon it) and (2) this would help the co-coder follow the flow of the dialogue more easily since he would only be coding portions of the larger conversation. Thus, the co-coder was only responsible for providing function codes for deriving the inter-rater reliability values.

Once the process of coding for inter-rater reliability was begun, the co-coder sent finished coding documents to the researcher for checking. The researcher recorded the number of codes on which the co-coder and researcher did not agree and the turn numbers for each point of disagreement. The co-coder and researcher met once a week over a three week-period to resolve their differences and come to agreement on the codes. [This also involved some level of refinement of the codes to provide greater precision related to the criteria for their application.] Once agreement had been reached, the document on which these resolved codes had been recorded became the final coding document for that particular MSP enactment.
Table 5: Information about Segments Co-coded for Inter-Rater Reliability Determination

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Period</th>
<th>Coded Moves in Lesson</th>
<th>Segments Coded</th>
<th>Moves in Segments</th>
<th># of Codes Not Matching [line #'s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hannah</td>
<td>1</td>
<td>147</td>
<td>C</td>
<td>30</td>
<td>3 [42, 46, 59]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td>7</td>
<td>1 [40.a.(4)]</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>134</td>
<td>B</td>
<td>14</td>
<td>1 [35.g.(15)]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>206</td>
<td>E</td>
<td>9</td>
<td>2 [239, 251]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>29</td>
<td>5 [257, 259, 273, 274, 286]</td>
</tr>
<tr>
<td>Marty</td>
<td>4</td>
<td>123</td>
<td>C</td>
<td>52</td>
<td>4 [92, 108, 109, 121]</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>188</td>
<td>I</td>
<td>35</td>
<td>4 [313, 316, 328, 371]</td>
</tr>
<tr>
<td>Nancy</td>
<td>3</td>
<td>69</td>
<td>C</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td>5</td>
<td>1 [171]</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>86</td>
<td>F</td>
<td>30</td>
<td>6 [164, 170, 171, 172, 191, 192]</td>
</tr>
<tr>
<td>Sandy</td>
<td>3</td>
<td>67</td>
<td>E</td>
<td>16</td>
<td>3 [77, 82, 87]</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>60</td>
<td>G</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>71</td>
<td>C</td>
<td>31</td>
<td>7 [52, 53, 55, 62, 63, 71, 72]</td>
</tr>
</tbody>
</table>
Table 5 (cont.): Information about Segments Co-coded for Inter-Rater Reliability Determination

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Period</th>
<th>Coded Moves in Lesson</th>
<th>Segments Coded</th>
<th>Moves in Segments</th>
<th># of Codes Not Matching [line #’s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarah</td>
<td>1</td>
<td>93</td>
<td>F</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td>8</td>
<td>1 [183]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>9</td>
<td>3 [195, 198, 200]</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>103</td>
<td>D</td>
<td>31</td>
<td>3 [158, 175, 176]</td>
</tr>
<tr>
<td>5B</td>
<td>124</td>
<td>B</td>
<td>59</td>
<td>13 [99, 100, 103, 104, 105, 105, 107, 108, 110, 114, 126, 139, 157]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>C</td>
<td>16</td>
<td>2 [145, 146]</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>1535</td>
<td>407</td>
<td></td>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>

There are two important results to cull from the data presented in the table presented over the last two pages. The first is that out of a total of 1535 moves from the entire corpus of data receiving the main function codes, 407 (26.5 %) were part of the data used to derive the inter-rater reliability value. The second is that, out of those 407 moves across the fourteen discourse analysis documents to which the main function codes were applied, the codes generated by the researcher and co-coder matched in 347 of the instances (with the other 60 being resolved by discussion as described above); this correlates to 85.3 % agreement which is above the 80 % mark normally seen as acceptable in this kind of discourse analysis work (Fan and Chen, 1999; Marshall & Rossman, 2006; Silverman, 2004).
Presentation of Data

The challenge of this chapter is to be able to convey the information needed to answer the research question – i.e. to describe the specific nature of the interactions found in the data analyzed and to relate that to both the way ideas were explored and the structure of activity within the lessons studied – while at the same time being able to elucidate the more general features of the manner in which each teacher instantiated this lesson structure, and of similarities and differences between these instantiations. The organization of the data which seemed to lend itself best to accomplishing these dual objectives was to begin by providing some general information about the ‘settings’ in which the lessons took place, then to run through all of the data for each teacher’s set of enactments individually (in the form of a mini ‘case study’ (Merriam, 2002) of each teacher), and finally to present some overall data which could offer some numerical comparisons between different lessons from the same teacher and between different teachers. Within the case study for each teacher, there will be the following sections of information: (1) brief sketch of the teacher based on the interviews; (2) overview of the way the problem-solving activity was framed for the students; (3) description of the way the activity was structured in the lesson through review of the Solution Pathway Maps (SPMs); (4) examination of key interactions which took place within the lessons and their associations with progressive discourse, idea development and the structure of activity; and (5) overview of the way the activity was brought to a close through the formalizing of the scientific explanation.

Before this presentation of the data is begun, it is important that the reader know that the order in which the case studies will be presented is a function of the relationships between the structure of activity used by the different teachers – relationships which will become more obvious as the SPMs for this group of teachers are more thoroughly scrutinized.
The Settings for the MSP Enactments

The Schools

One of the things which will clearly limit the generalizability of any findings derived from this study is that there was tremendous similarity among the four schools in which the five participant teachers worked. All of the schools served smaller rural or residential communities and housed student populations that were 99% or more Caucasian in make-up. Each of the schools met the No Child Left Behind Adequate Yearly Progress (AYP) requirements for the 2007 – 2008 school year (the year in which the video and interview data was collected; see www.paayp.com/ for details of the requirement guidelines), indicating that each is in good academic standing. Where there is some variation is in the size of the schools and in the economics of the local communities. The table below presents this information for each teacher’s school using the high-school enrollment (as of 2006, the year before the study) to represent size and the median value per housing unit as an indicator of the local economy (data was obtained from http://nces.ed.gov/surveys/sdds/ and based on 2006 statistics).

Table 6: Size and Local Economics Data for Schools at Which Data Was Collected

<table>
<thead>
<tr>
<th>Participating Teachers in School</th>
<th>High School Enrollment</th>
<th>Median House Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nancy</td>
<td>301</td>
<td>78,800</td>
</tr>
<tr>
<td>2. Marty</td>
<td>674</td>
<td>89, 100</td>
</tr>
<tr>
<td>3. Sandy and Hannah</td>
<td>707</td>
<td>93,300</td>
</tr>
<tr>
<td>4. Sarah</td>
<td>1,227</td>
<td>122,500</td>
</tr>
</tbody>
</table>

This data indicates that Nancy’s school was by far the smallest (being classified as a single-A school in the Pennsylvania system) and had the lowest average property values and that
Sarah’s school was by far the largest (being classified as a triple-A school in the Pennsylvania system) and had the highest average property values, with Marty’s, and Sandy’s and Hannah’s schools being in the middle and very close in those two categories.

**The Lessons**

In this sub-section, the reader will be provided contextual information about the nature of the lessons – the problem under investigation and other relevant content – needed to understand aspects of the discussion which will occur in subsequent sections. The four female teachers all used the same problem as the centerpiece for their lesson and so their lessons will be discussed as a set; Marty used a different problem and so his lesson will be considered separately.

**The Zinc – Sulfur Reaction Lesson**

As was explained in the *Introduction*, the seed for this entire research project was a single lesson developed by the researcher while he was still a classroom teacher. The lesson revolves around a problem presented to the students by the teacher: Given a certain amount of the element zinc (Zn), determine the amount of sulfur (S) necessary to react with it. A rationale for the students to invest the effort needed to solve the problem is also given: This reaction is used in model rocket engines and so a mixture with the proper ratio will produce a tremendous amount of heat (and light) energy.

While the reader will not need a chemistry degree to understand the conversation that occurs around solving the problem, some understanding of the chemistry involved in the reaction will prove useful. In word form, the equation for the reaction of interest is . . .

Zinc and sulfur make zinc sulfide

In symbolic form, the equation for the reaction of interest is . . .

\[
1 \text{ Zn} + 1 \text{ S} \rightarrow 1 \text{ ZnS}
\]
An important part of the equation is the presence of the ‘1’s’ (the coefficients of the balanced equation) in front of the symbols of the chemical species involved. Interpreted properly, they indicate that one mole of zinc will react with one mole of sulfur to produce one mole of zinc sulfide in the ideal situation. The significance of this is that students will often misinterpret the meaning of those ‘1’s’ and produce less successful solutions to the problem. This tendency in student thinking will play a key role in the discourse in Sandy, Sarah, and Nancy’s classes.

It is also vital that the reader understand the importance of the word choice “less successful solutions” in the previous paragraph. The ideal mixture – one mole of zinc and one mole of sulfur – will – theoretically – generate its heat and light energy in the most facile and efficient manner, and therefore produce the most visually impressive reaction. However, a wide range of other possible combinations will also produce mixtures which will ignite and give off the same amount of heat and light – just not as quickly and efficiently. This fact ends up playing a major role in the results of the empirical testing of proposed solutions and has a profound effect on the way those test results are evaluated by the teachers and students.

While the four female teachers were ostensibly doing the ‘same lesson’, it is obvious that these lessons were going to be different from each other simply based on the fact that they were taught by different teachers with different classroom cultures in different schools. Beyond these very salient factors, though, there are a few other factors that made the lessons different in each of the classrooms. The first of these is the content background that the students had coming into the lesson. Nancy was the first one to conduct this lesson and her students had the least amount of pertinent background information as a result of this fact. Whereas the other teachers had all covered material related to understanding chemical reactions prior to presenting this lesson, for Nancy, this lesson was placed at the beginning of a unit on this topic. Hannah and Sandy – as
noted in the previous sub-section – had largely synchronized their schedules and both had just completed a unit on chemical reactions. For these two, the Zn-S reaction lesson marked the beginning of a section on the mathematics of chemical reactions.

Sarah’s students had by far the greatest amount of content background (hers were the last set of lessons to be videotaped). Not only had she covered the basics of chemical reactions, but she had already moved through a couple of lessons on the mathematics of chemical reactions. In fact, Sarah had already familiarized her students with the ‘mole’ interpretation of the coefficients. This large disparity in background information contributed to the second difference in the lessons: The researcher suggested to Sarah to give the students a different mass of zinc to present to the students as the starting amount of this chemical. While the other teachers gave their students a starting mass of ‘6.54 grams’ of zinc, Sarah gave her students ‘13.00 grams’ as the starting amount. The significance of this difference is that it is much harder for students to determine the appropriate amount of sulfur given ‘13.00 grams’ than it is given ‘6.54 grams’.

The final difference between the lessons of these four teachers will be introduced here and then developed in some detail within the framework of each teacher’s case study: Sandy, Sarah and Nancy all had very similar structures to the activity within their lessons, while Hannah had a very different structure to the activity within hers. The students in Sandy’s, Sarah’s, and Nancy’s classes spent less time in small-group work (usually only the one or two Generating Proposals segments) than did the students in Hannah’s classes. Within those small-group activity segments, Sandy, Sarah, and Nancy did not interact with the students, while Hannah did. Finally, and most importantly, in the Sharing Out segments that followed these small-group portions of the activity, only a couple of groups offered solution proposals in Sandy’s, Sarah’s, and Nancy’s classes, while all groups were expected to provide proposals in Hannah’s classes.
The Periodic Trends Lesson

Not only was Marty’s lesson different in terms of the content of the problem he posed to his students, but it was different in terms of the fact that Marty proposed this as a representative MSP lesson himself (as opposed to the fact that the researcher had suggested the Zn-S reaction lesson as a representative example to the other four participants). The problem in Marty’s lesson was for students to predict the trend in the atomic radii (i.e. the size of the atoms) down a family and across a period for two sets of assigned elements (one for the family and one for the period). It is important before discussing the nature of this problem further to present to the reader Marty’s rationale (from interview 1) for choosing this as his sample MSP lesson:

Researcher: Before moving on, I wanted to ask you what it was about that [the activity] that you saw as potentially representative of [the MSP]?

Marty: Well I was really – and I told you this in the e-mail – that I thought about this for a while and nothing really came to my mind. And then I was going through my plan book and seeing what I did – trying to come up with something that I know the kids often kinda ‘go down that wrong path.’ And that was one of the first things that I came to that I could be certain – that I know – that they’re probably going to go down that wrong path.

Marty’s choice of the content for this lesson seems quite appropriate given that it involves a problem for which there can be multiple solutions (at least three – increase, decrease, or stay the same – related to the prediction of the trend in atomic radii – and many more relative to possible explanations of the predicted trend) and given that it is a problem having an accepted solution which should be within the students’ zone of proximal development (Vygotsky, 1978, 1986). It is important, though, that the reader recognize that Marty’s portion of the above excerpt indicates a different rationalization for the validity of this choice: a focus on the possibility of students running into a ‘dead end.’ The researcher discussed with Marty the distinction between the larger MSP construct and the smaller ‘dead end’ component of that construct following this first interview. It is likely, however, that Marty maintained his fixation
on the ‘wrong path’ aspect of these lessons as he engaged in his enactments – a likelihood indicated by the discourse data from his lessons which will be examined later.

While Marty had covered this same content every year prior to the videotaping of this lesson, his interactions with the researcher in the time leading up to it had prompted him to conduct the lesson differently and he had produced a vision of what this enactment would look like. In this vision, after providing the appropriate background, Marty would split the class up into its normal lab groups and give each group a set of elements representing one of the families on the periodic table (each group was given a different family). Each group would draw Bohr models (based on a picture of the atom that is not quite the most modern one, but is more accessible to the average high school student) for each element in their family. They would then predict the trend in atomic radii for their family and place their drawings in an order matching that trend. Next, they would present their predictions to other members of the class. This same sequence of steps would then be repeated for a set of elements representing a period. Finally, Marty would discuss with them the actual trends down a family and across a period.

One concern that the researcher conveyed to Marty about his vision is that it offered no means for students to empirically test the validity of their proposals or to evaluate the results of that test. This lead Marty and the researcher to co-construct such a means based on available resources and time constraints. (The dialogue around this co-construction was reified in the interview 3 transcription.) It was determined that students would be issued a packet containing a list of all of the main group elements (only those included in the sets of cards the students were given) and data for various properties of those elements – including atomic radii – to use after they had made their predictions to check the accuracy of those predictions. This approach had the value of requiring an investment of effort on the part of the students in terms of looking up
the appropriate data, organizing it according to family and period structure, and interpreting its meaning. As it turned out, this approach had a major – and unexpected – impact on the way the activity unfolded.

*The Lesson ‘Case Studies’*

*Sandy’s Lessons*

*A Sketch of Sandy*

There are at least two points on which Sandy sets herself apart from the other participants: The first is that she had the greatest amount of in-service teaching experience of any of the participants and the second is that she had the longest-standing relationship with the researcher of anyone involved. Regarding the second point, Sandy and the researcher had been colleagues for twelve years prior to the researcher resigning from his position as a high school teacher. Their relationship went through a significant transition during that time period, with it being contentious in the early years because of differences in teaching philosophy and becoming much more collegial in the later years resulting in her unqualified willingness to participate in this study (as well as a pilot study which had occurred the year preceding this investigation).

Sandy’s teaching responsibilities include two chemistry courses – Chemistry I and Chemistry II – and Oceanography and Meteorology. It is important to note that Sandy and Hannah co-teach the Chemistry II course and that, as a result of that collaboration, they have also largely synchronized the content and sequence of presentation of the content in the Chemistry I course. Thus, the students in their respective classes came into the sample MSP lessons having very similar subject matter backgrounds.

Within both the pre- and post-lesson interviews, there was a recurring theme that provided a valuable lens for understanding the way in which Sandy’s enactments might / did
play out. This theme first surfaced in interview 1 (section B.2) in response to a question from the researcher about Sandy’s confidence in conducting a more open-ended whole-class discussion – exactly the kind of discussion one would expect to see in a genuine MSP instantiation:

Sandy: As far as a big class discussion about some concept where everybody’s contributing, that doesn’t happen a lot in my class.

Researcher (probe question): So, you’re not comfortable with it [open discussion] in a large . . . or you don’t feel . . .

Sandy: I’m not good at it . . .

Researcher: In a large [group] setting . . . so is that . . .

Sandy: No, in a large setting, I don’t think so.

Researcher: It’s not conducive [the large setting] to it [open discussion]?

Sandy [bluntly]: I’m not good at it.

Related to this Sandy noted (interview 2, section B.2) that when “I teach I am much more task-oriented than student-oriented.” That task-oriented nature is a reflection of her “need to be able to know what kinds of things I should say – because I . . . I practice it” (interview 2, section B.2), which limits her ability to build the conversation off of unexpected – but meaningful – discourse contributions from students: “Now I can do a little more ad-libbing” (interview 2, B.2). Sandy’s concern with being fully prepared in terms of what to say during the course of the lesson caused her to construct a script from the pre-lesson discussions between her and the researcher: “I actually found myself Thursday morning when I was brushing my teeth, planning out what I was going to say to the kids” (interview 3, A.3). It will be important to keep in mind the existence of this internal script as the data regarding the nature of the interactions in Sandy’s lessons is examined.

Solution Pathway Maps

Probably the most conspicuous feature of the SPMs for the first two of Sandy’s three enactments of the Zn-S lesson (periods 1 and 3; see Appendix G) is the extremely linear structure
of the activity within them – there are no indications of the “circuitous paths” of “the course of inquiry” that Colapietro (2000) describes (quoted in the Introduction). While this could be an artifact of the way the researcher chose to represent the activity in these diagrams, it is really a function of the manner in which ideas were explored in these two classes: After the problem was presented, an initial proposal (6.54 grams, equal mass – in both classes) was made, it was tested, found to be untenable, the flaw in the logic leading to that proposal was identified, a more logical proposal was derived (largely through Sandy’s guidance), this second proposal was tested and found to be quite tenable, and then the scientific explanation for why the first proposal failed (or was less successful) and the second proposal was more successful was given.

Following the second (period 3) enactment and prior to the third (period 7) enactment, the researcher discussed with Sandy the possibility of giving students more of a chance to generate a set of different ideas in the final instantiation. This resulted in a Generating Proposals segment lasting one minute and two seconds in period 7 (vs. 15 seconds in period 1 and 5 seconds in period 3); it also resulted in an activity structure that was somewhat more complicated as three different ideas were proposed and connections between those ideas were made by students (and this is reflected in a more complex SPM – at least in the middle section of the diagram). Interestingly, though, from the point of Conducting Test I on, the SPM for period 7 is exactly the same as for the other two classes. There was a bit of serendipity which was responsible for this – serendipity which happened to coincide with the script that Sandy had in mind for this lesson. Sandy discussed this in an interview (3, section B.1) in response to a question about the way events unfolded in the three enactments:

Researcher: Were you surprised by the thinking they went through? Were there any people that made contributions that you might not have expected to or . . .?

Sandy: No, I don’t think so. I think it was mostly what I expected – what I expected they would do. I think it was what I expected they would do [with me]
doing it differently – except for the three different values in the class. When that happened I was like, ‘Okay, gotta think, gotta think, gotta think.’

Researcher: So that was a really important moment for you – you were really caught off guard by that?

Sandy: Yeah. I was just [like], ‘Okay, now what . . . How am I going to get them to pick one?’ And I didn’t . . . I was thinking, ‘How am I going to get them to pick the same amount [of sulfur as zinc]?’

Researcher: Oh, so you wanted them to pick the same amount?

Sandy: I wanted them – the first time I wanted them to, because I wanted it to go wrong.

As will be discussed in chapter 5, this excerpt has implications related to what notions Sandy likely had of what students were going to do and how this kind of lesson should be implemented. There is one other feature of the SPMs that speaks to this same point: One will notice that after the first Analyzing the Test segment in each of her three classes, there is a segment labeled Explaining the Dead End – a segment unique to her enactments. In each of those three lessons, this activity segment was begun with a turn similar to this one from period 3:

75. Sandy: So what must be true about why – why do you think it didn’t work?

The different variations of this question (the other two being found in line 86 of period 1 and in line 117 of period 7) all set a very specific goal for this segment of the activity: To consider the reason that the first solution did not work – in other words, to treat this as a failed attempt (a dead end) from which something can be learned that may help in formulating future proposals.

It will be important to compare analogous goal-setting turns in similarly-positioned segments from other teachers’ lessons to see if they established the same objective for such segments.

Framing the Activity

There are four main features of the Building Up the Problem segment of Sandy’s lessons to be addressed. The first is that she devoted a great deal of attention to connecting the activity
to the larger storyline of the course, as this excerpt from her period 1 transcript shows:

1. Sandy: In this chapter, we’re doing stoichiometry. Maybe you saw there was a mole [puppet] on the front page of the notes – this is mole math. You have been building up to this chapter. It started with the ion quizzes. Then you learned about electron configurations, and how atoms form ions. And we related that to the periodic table: properties of elements and where they are on the periodic table. Then you learned how atoms form bonds, and the types of bonds they form – which was related to their position on the periodic table and their electron configurations. Then you learned how to name the compounds and put the compounds together in balanced equations. So you did that last chapter. Now it’s time to put all that together and make the chemistry work for you.

The second feature is that she put a substantial effort into trying to create a mental picture of a successful test through the dialogue in the framing segment, as this pair of exchanges (from the Pd 3 transcript) indicates:

1. Sandy: So today our demonstration is a mixture of ingredients that – when they react properly – can be used to fuel a rocket. So what are you expecting this reaction to do? If it can fuel a rocket, what would you expect when the reaction works?
2. Unknown female student: Blow up.
3. Another unknown female student: Catch on fire.
4. Sandy: Right. You want some fire, you want an explosion, you want a lot of what released?
5. MS 1: Energy.
6. Sandy: Energy. So if you balance your equation correctly, and then you figure out your math – your amounts – correctly, you will get a very exothermic reaction. You will get a lot of energy released – a lot of power – that could propel your rocket. If you don’t measure correctly, [noise with tongue], it won’t work.

It is important to note that Sandy’s final statement in this sequence suggests that a non-ideal mixture “won’t work”, which is incorrect information and actually presents a challenging situation for her when such a mixture does [eventually] ‘work’ – and work quite well – in her period 3 class.

The third feature to discuss is that Sandy made one of the two main cognitive tools needed to solve the problem – the balanced chemical equation – quite salient to students by
(1) devoting a substantial number of turns in the Building Up the Problem segment in each class to constructing the equation (21 turns in period 1; 27 turns in period 3; and 29 turns in period 7) and (2) by writing the information about the equation on a white board which was in the center of the work area in which the activity took place. By comparison, the other essential cognitive tool – the periodic table – was not at all salient to the students as the only one that was available (since students did not have their books out) was several feet behind where they were sitting.

The final feature of Sandy’s framing effort to point out is that she made no mention of the process by which ideas would be explored and the problem-solving activity would be conducted in this segment. Therefore, the students would have had to assume that this process would occur through the typical forms of interaction built up in the months preceding this lesson and would have had no expectation that there would be any variation from standard classroom practices.

*The Nature of the Interactions*

Before beginning a discussion of interactions occurring in Sandy’s lessons, it is important to address a more general issue related to this portion of each teacher’s case study. Obviously, in every lesson which was videotaped and analyzed, there were hundreds of interactions that transpired, and therefore decisions had to be made related to which limited set of these interactions would be presented as data. Those decisions were based on the concern for understanding the manner in which these interactions provided (or failed to provide) opportunities for students to explore their ideas and supported (or failed to support) the commitments of progressive discourse. Thus, the interactions selected for presentation were those that were relevant to this focus and represented patterns related to these features of the classroom activity. When each interaction is given, some context will be provided regarding which of these features it addresses and how it is related to that feature.
To begin this discussion, consider (and compare) the following two excerpts, both taken from the first sequence in the Proposing Solutions segment of their respective lessons – the first from Sandy’s period 3 class and the second from her period 1 class (the period 3 excerpt is presented first because this lesson took place one day before the period 1 lesson):

35. Sandy [continuing from line 34]: Now, to start with, we need an amount, and I have chosen ‘6.54 grams’ of zinc. [Writes on board.] So you need to decide some number of grams of sulfur that will make this reaction work the best. [Writes ‘___ g S’ to represent the problem.] So, what do you think that would be?

Nuc. I Req. I / P

36. MS 1: ‘6.54’
Nuc. R Give I / P

37. Sandy: ‘6.54’.
Nuc. F Accept.


38. MS 6: Yeah.
Dep. R Sup. I / P

39. MS 7: Yep.
Dep. R Sup. I / P

And:

31. Sandy: All right. So, how much are we going to use?
Nuc. I Req. I / P

32. Unknown male student: Same amount [of sulfur as zinc].
Nuc. R Give I / P

33. Another male student: <‘6.54 grams’.
Nuc. R Give I / P

34. Sandy: <Same amount. ‘6.54’.
Nuc. F Accept.

Anybody come up with a different number?
Dep. I Req. Alt.

35. [No response]

36. Sandy: All right, ‘6.54 grams’. [Writes this on board] Why?
Dep. F Reify Contr.


37. Same male student as 33: Because it’s balanced.
Dep. R Give Just.

38. Sandy [3 seconds after 37]: All right, because it’s balanced.
Dep. F Appr.

Even though both of these excerpts come from the same point in the lesson (in terms of the structure of activity), there are two entirely different sets of interactions as a result of the use of different dependent-exchange initiation moves by Sandy. In the first excerpt, there is a
request for evaluation (of the proposal) in the initiation move of the dependent exchange (line 37); there is no request for alternatives (supportive of the expansion commitment) or request for justification (supportive of the openness commitment). Further, because the request for evaluation came without a request for justification, the only thing the other students could evaluate was the idea itself – not the reasoning behind it. In the second excerpt, there is both a request for alternatives (line 34; initiating the first dependent exchange) and a request for justification (line 36; initiating the second dependent exchange. This allows both for other ideas to be offered (although none are) and for the individual providing the first idea to give the reasoning behind it. However, without a request for evaluation, the other students in the class do not have the opportunity to critically examine either the idea or the reasoning.

In addition to the significance of the presence or absence of certain discourse moves in terms of the way students’ ideas are explored, it seems likely that the sequence in which certain moves are employed could be influential in this process. For instance, does it matter that Sandy’s request for alternatives came before the request for justification instead of after it? This is an open question that will be revisited during the discussion of the interactions which occurred in Sarah’s lessons.

In the SPM sub-section, it was noted that a unique situation arose in Sandy’s period 7 class (compared to her other two classes), as more than one idea was offered in the Proposing Solutions segment. This allowed for a different set of possibilities related to the interactions taking place around the exploration of students’ ideas, and it is important to examine which of those possibilities became actualized. One feature of that actualization is evident in the following three sequences from the beginning of the Proposing Solutions segment in this class:

*Sequence 4*
37. Sandy: All right. [Pointing to group just to left of camera] So what do you think? Prep. I

Nuc. I Req. I / P

38. FS 2: ‘3.22’

Nuc. R Give I / P


Nuc. F Ack.


40. FS 2: I don’t know.

Dep. R Un Meet Req.

41. FS 3: That’s just what we came up with. [Laughs while saying this.]

Dep. F Un Meet Req.

Sequence 5

42. Sandy [Pointing to group near middle lab station]: What do you think? Prep. I

Nuc. I Req. I / P

43. MS 4: We’re going with the same amount. Nuc. R Give I / P


Dep. I Req. C / E

45. [MS 4 nods his head] Dep. R Give C / E

46. Sandy: Yeah [indicating she has correctly interpreted this] Dep. F Accept.

Sequence 6

47. Sandy [to last group, to far right of room]: What do you think? Nuc. I Req. I / P

48. MS 1 [6:21]: Uh, he . . . he’s [his partner] checking out, uh, Emb. I

Nuc. R Give Just. sulfur’s atomic number right now because for every one

should be one part, uh . . . sulfur.

49. Sandy: Okay. So, we have to wait for his [the partner’s] thoughts. Emb. R

50. MS 5 [from in front of room near P.T.]: ‘32.06’ Nuc. R Give I / P*

[*This is coded as such because, even though this was simply meant to be a piece of information that MS 5 was delivering to his partner, it became accepted as the group’s proposal for a value.]

The most significant thing to recognize within this set of exchanges is the way in which requests for and give justification occur. In sequence 4, Sandy makes a request for justification related to FS 2’s idea – the only time she makes such a request in this set of sequences. (The fact that FS 2 and 3 are unable to provide such a justification will become important in the next set of
interactions which are examined.) In sequence 6, MS 1 provides a justification – before Sandy asks for one and even before he and MS 5 have finalized the determination of their proposal. In sequence 5, no request for justification is made by Sandy, nor do the students in the presenting group spontaneously offer one. Before leaving the discussion of this set of data, it is important to note that in a later pair of sequences in this segment (7 and 8), when these proposals are all revisited, Sandy once again makes only one request for justification (out of three opportunities to do so) – and once again it is made to the group proposing the ‘3.22 gram’ solution.

Going into the next excerpt, it is important that the reader keep in mind two of the points made in the preceding paragraph: (1) That during two different sets of sequences, Sandy only made a request for justification of the group proposing the ‘3.22 gram’ solution and (2) that the first time this request was made, neither FS 2 or FS 3 (two of the members of this group; MS 6 is the third) was able to provide a justification. With these facts in hand, consider this next extract which picks up the dialogue at the point at which the previous excerpt left off:

51. FS 2: Well, we were close [referring to their value only being off a decimal place from MS 5’s proposal]!

[*This represents a positive evaluation of MS 5’s proposal as reflected by the fact that the validity of the group’s proposal is being based on a comparison to this other proposal.]

52. FS 3 [laughing while she speaks]: No, we said ‘3.22’!

53. Unknown male student: How we’re you close?


55. FS 3: It was ‘28.’ [off]

[**This is either a follow-up to her own response in 52 or to the male student’s response in 53.]

56. MS 6 [to FS 2]: Did you mean ‘3.27’ – to be half [the amount of zinc]? Is that what you meant?

57. FS 2: I don’t really know what I meant. [Laughs]

To fully appreciate the significance of the interactions taking place here, it will be necessary to look at another excerpt which was found slightly later in the segment. Before doing
so, though, it is important to note that this excerpt began with FS 2 making a connection between her group’s idea and the one proposed by MS 5’s group – the kind of interaction which did not appear in either of Sandy’s other classes where only one idea at a time was presented. Further, in forging that association, FS 2 initiates a pair of exchanges which ultimately result in MS 6 (who is in the same group as FS 2) suggesting both a slight modification to this group’s proposal and a possible justification for that proposal. Besides the impact this pair of exchanges has on this group’s thinking regarding their own idea – which will show up in the next excerpt – the fact that MS 6 asks this question may indicate that the members of this group were not given sufficient time to develop their idea and make sure everybody was ‘on board’ with it during the Generating Proposals segment (which the reader is reminded only lasted a little over a minute).

With the discussion above in place, it is now possible to consider the more long-range effect of the interactions in the previous excerpt by examining this extract from a subsequent sequence in the Proposing Solutions segment:


60. FS 3 [7:20]: <‘3.27’.

61. FS 2: <We . . . We were trying to go half.

62. Sandy: You were trying to go half.

Why did you want to go half?

63. FS 3 [after 4 sec. pause]: Because we thought it was either the same as that [the amount of zinc] or half of that.

64. FS 2: And they said ‘the same’ [referring to middle group].

65. FS 3: So we went with half. [Laughs]

66. Sandy: So . . . just so you can be different than the other group?

67. FS 2: Yeah.
This segment begins with a turn by Sandy alluded to earlier in which she makes her second request for justification for the ‘3.22 gram’ proposal (without making one for the ‘6.54 gram’ proposal even though she mentions this other proposal in the same turn). The first point of interest from this excerpt is FS 3’s overlapping utterance in line 60 in which she attempts to modify this group’s proposal in accordance with the value suggested by MS 6 back in line 56. Just as significantly, in the set of turns from line 63 – 65, FS 2 and FS 3 provide a justification (with some clarification) for their idea where none previously existed, again in line with what MS 6 had put forward in line 56. Thus, what started as a simple comment in which FS 2 made a comparison between her group’s idea and another group’s idea turned into an ad hoc modification and justification for this group’s original proposal. While no one would argue that this represents a good model of scientific thinking, it reveals the additional possibilities in terms of the way ideas can be explored in a classroom when multiple proposals are put out there by students and they are given the opportunity to examine and compare those proposals.

Moving on to a consideration of the interactions which occurred in later task segments, it was noted in the SPM sub-section that Sandy had a segment unique to her lessons – Explaining the Dead End – in which the goal was to account for why an untenable solution (each time, the equal-mass proposal) might not have worked with a view towards formulating a better solution. That segment always began with a turn from Sandy – like the one presented in the SPM discussion – which contained a question making this goal explicit. To examine the interactions taking place in that segment, it seems appropriate to look at the entire sequence from which Sandy’s turn in the SPM-discussion example was taken (and which was found in period 3):

75. Sandy: So what must be true about why – why do you think it didn’t work?
The first point to be made about this excerpt is that the exchanges that transpired following the posing of the critical question in line 75 likely did not involve the kinds of interactions which Sandy intended, as her question was designed to elicit ideas about the flaw in the reasoning used to generate the initial proposal and the students instead started randomly suggesting alternative solutions. Sandy allows this to go on for several turns before using a re-utterance and a re-formulated request for ideas to try to get students back to thinking about the reasoning behind the generation of proposals. She brings this concern with using reasoning over making uninformed guesses further into focus with the final pair of exchanges in this sequence (before a flare-up of the first test mixture interrupts this segment) – particularly her re-utterance in line 85. Thus, Sandy makes a significant use of the re-utterance move within this set of exchanges to move the discussion towards a more reason-based analysis of the problem.
As indicated above, this task segment was interrupted by a flare-up of the first test mixture and a discussion of that event. Following that interruption, the conversation returned to the effort of trying to explain the dead end. However, upon that return, the nature of the interactions changes, as this excerpt from later in the same class period (3) should show:

101. Sandy: Now, the reaction didn’t work as well as you wanted it to the first time. If you get the right mix, it will go the first time, very quickly, and it won’t keep, you know, dying out and coming back, dying out and coming back. Because you don’t want . . . If you’re baking a cake, you want it — when you put it in the oven, you want it to just keep cooking. You don’t want to have to keep taking it out and putting it in, taking it out and putting it in, taking it out and putting it in, because it’s not going to rise and get all nice. So you want it to go correctly the first time and this is where the math comes from. So, equal grams of zinc and sulfur won’t work. But it is a ‘one-to-one ratio’ in the balanced equation. Let’s see why this doesn’t work. If you add ‘6.54 grams’ of zinc to ‘6.54 grams’ of sulfur, how may grams of zinc sulfide are you going to get?


103. Sandy: Okay, so you’re going to have ‘13+’ grams of zinc sulfide. All right, ‘13+’ – more than ‘13.’ Okay, because I ran out of space, plus I can’t do all of that math. Good thing I went to school before the math PSSA’s.

104. [Students laugh]

105. Sandy: Okay, so you’ve got more than ‘13.’ Now, there should be some things that aren’t sitting right with you with this number. How did you choose this ‘6.54’ [for sulfur]?

106. FS 3: It was a ‘one-to-one’ ratio.

107. Sandy: It was a ‘one-to-one.’

As opposed to the more open kinds of questions that Sandy posed in the Explaining the Dead End segment before the interruption, in the return to this task the questions became more closed and guided. Sandy seemed to signal this change in interactions with her statement, “Let’s see why this didn’t work” in line 101. Further, after her statement, “Now, there should be some things . . .” in line 105, instead of asking a question which might have allowed students to
identify what those “things” were themselves, Sandy used a query that begins a very carefully-crafted line of reasoning in which she herself made very obvious what the main thing is – that students have misinterpreted the meaning of the coefficients in the chemical equation. In the movement through this reasoning, students are engaged in the thinking necessary to recognize this flaw only to the extent required to fill in the answers to the slotted questions regularly posed.

This segment culminates in an exchange in which a new solution is proposed:

133. Sandy [after writing atomic mass values for Zn and S on the board]: [Dep. – F to lines 128 / 130; Reify. Contr.] So, I chose ‘6.54 grams’ of zinc; how many grams of sulfur are going to work? Nuc. I Req. I / P

134. MS 1 [14:51]: ‘3.2’ Nuc. R Give I / P

135. Sandy: ‘3.21’ So, if that’s the real ratio that follows the balanced equation, we should get a better reaction. Nuc. F Accept. Give Pred.

Even though MS 1 ostensibly offers this proposal in line 134, Sandy has developed all of the reasoning which led to this solution. Beyond taking that responsibility out of the hands of the students, Sandy goes on to make a prediction about what the larger line of reasoning constructed in this segment should indicate about the results of testing this new proposal (line 135).

The exact same pattern of interactions just described (including a Give Pred. by Sandy in line 164) was found in Sandy’s period 1 class. In her period 7 class (where multiple solutions were proposed initially by students), the situation was slightly different as students made contributions which helped advance the key line of reasoning in the Explaining the Dead End segment which went beyond just filling in answers to slotted questions, as this excerpt shows:

117. Sandy: So now we have to figure out why this didn’t work. Nuc. I* Req. I / P

118. MS 1: It needs to be proportionate to the atomic weight. Nuc. R* Give I / P

[*Even though Sandy’s statement in 117 was not voiced as a question and was probably not meant to be a Req. I / P initially, it was treated as such by MS 1.]
There is not necessarily a causal connection between the difference in the way the Sharing Out segment unfolded in this class and the difference in the nature of such interactions in the Explaining the Dead End segment. Still, because the nature of these interactions was so different in period 7 from the other two classes, it is important to be cognizant of the differences in the larger context in which they occurred.

*Formalizing the Solution (FtS)*

Given the potential complexity of the MSP lesson structure – with the possibility of following several proposals through the set of steps needed to determine their efficacy – it seemed important that, as the lesson came to a close in this segment, the scientifically-accepted explanation usually developed here was used to account for both tenable and untenable solutions. This, then, became a point of analysis in examining the discourse in this segment.

As noted in the SPM discussion for Sandy’s lessons, there were always two solutions that were proposed and tested: The equal-mass solution (which was tested first and found largely to be untenable) and the solution based on ratios of atomic masses (which was tested second and always found to be tenable). Sandy’s discussion in the FtS segment was strongly aligned with this set of circumstances, as she made sure to connect the normative explanation to both solutions, and to discuss why one worked and the other didn’t. These connections are clear in a pair of excerpts from her period 1 class:

207. Sandy: . . . So if you are using the periodic table, you’ll get the ratios that are shown in the balanced equation, because it relates the atoms, okay – one-to-one atom ratios. Since zinc and sulfur aren’t the same size atoms, their masses aren’t the same. The only time you’d use equivalent masses to get something would be if they have the same mass – if they are the same size. And usually you don’t have that.

And . . .

233. Sandy: . . . Okay, so in our demonstration today, we started out with the
6.54 grams of zinc . . . Okay, so we had the solid zinc and the solid sulfur make zinc sulfide, and it’s a one-to-one-to-one ratio. And from the one-to-one ratio, you’re thinking I should have equal masses of them. Okay, that’s the first time, but did that reaction work well?

234. Several students: No.

235. Sandy: No. Okay, so it was a bad reaction. It was unreliable, unpredictable . . . So we chose the 6.54 grams of zinc with the 3.21 grams of sulfur and we got a spectacular reaction . . . Why did this one work better this time? Where did we get our numbers this time?

236. A couple of students: The periodic table.

Sandy clearly takes most of the responsibility for developing the connections, only allowing students to participate to the extent of filling in answers in slotted questions that she has provided for them. It will be important to compare this feature of Sandy’s approach to conducting the FtS to the way this was handled by the other three teachers doing the Zn-S lesson.

Sarah’s Lessons

A Sketch of Sarah

Sarah had a lengthy history of affiliation with the researcher and with the ICISS research group prior to her involvement in this study. She had been one of the first pre-service teachers to participate in the ICISS project, taking part in numerous meetings and research ‘retreats’ where group members discussed their work and struggled to conceptualize inquiry science teaching. Further, Sarah was mentored by the researcher, an experience during which she was supported by other members of the ICISS group. During that student teaching period, Sarah actually taught the same lesson which was videotaped for this study.

At the time the data was collected, Sarah was in her second full year of teaching in the school in which the videotaping took place (she had taught in a different school for a year prior to coming to her current school). Her teaching responsibilities involve just two courses: one section of physical science and four sections of Academic Chemistry (this is the ‘upper level’
chemistry course at her school; there is also a ‘lower level’ Fundamental Chemistry class). A very important note about the curriculum in that Academic Chemistry course (which is the class in which the sample lessons were conducted) needs to be made at this point: The content of that curriculum was completely prescribed by the Learning Focused Schools program which Sarah’s school had adopted (see www.learningfocused.com/); i.e. Sarah had no control over the content other than how she presented the material within a given lesson.

In interview 1 (section A.2), Sarah identified the Learning Focused Schools curriculum as one of three constraints which limited her ability to implement inquiry teaching practices; the other two were her minimal teaching experience (including being untenured) and her belief that she did not know the material well enough. She recognized these constraints as being in direct opposition – both practically and philosophically – to an essential feature of inquiry pedagogy:

The researcher asks Sarah why you have to know the material so well . . .

Sarah: Um, because you have to be able to take what they give you . . . which, you know, you have to be able to let go with inquiry, you really do have to let go of a lot . . .

Researcher: You have to let go of . . .?

Sarah: Of control, of where the lesson’s going to go. And you have to be able to think on your feet really fast, you have to be able to kind of steer them in the direction you want to go without, like, telling them the answer. Um, so I think you need to be able to think about tough concepts in a lot of different ways. Uh, and I know that I can’t do that right now. I can do that with some things – like the things that I did with you, but even with those things, it’s still tough for me. I think that’s a restraint that I’ve put on myself and it’s like, fear of the unknown.

(Interview 1, section A.2)

Perhaps because of this issue and others of a similar nature, Sarah showed a greater concern for engaging in discussions with the researcher about ways to translate the commitments of progressive discourse into classroom practice than any of the other participants. Responding to this concern and the concomitant sense of low self-efficacy Sarah projected, the researcher
followed up the last pre-lesson interview with a conversation about discourse strategies which might serve this need for Sarah. When looking at the data related to the interactions found in her enactments, it will be valuable to consider whether this support translated into Sarah being able to ‘let go’ of key features of the classroom discourse and turn them over to students so that they might ‘take control’ of the science talk in these lessons.

Solution Pathway Maps

Three of Sarah’s four lessons (periods 1, 3, and 7) had SPMs which indicated the same linear exploration of ideas found in Sandy’s first two lessons (periods 1 and 3). There were, though, a couple of differences in the structure of activity within these two sets of lessons. The first is that Sarah’s each contained an activity segment not present in Sandy’s lessons in which students were asked to work – first individually, then as a class – to develop a list of information from their prior knowledge in this course which might help in solving the problem. (This was positioned very early in the lesson.) The second is that Sandy’s lessons contained an activity segment not found in Sarah’s lessons in which the goal was to explain the untenable nature of the first solution which had been proposed. (This has been discussed previously.) The likely reason that this segment was absent from Sarah’s lessons is because it was unnecessary: In each of these lessons, the initial solution proposed was the accepted solution to the problem (a reflection of the more complete background Sarah’s students had going into the activity). Interestingly, in each of her first three classes, another solution – equal masses – was suggested for testing (largely to serve as a point of comparison): twice – in periods 3 and 7 – this suggestion was made by Sarah and once – in period 1 – it was made by a student. Sarah’s reason for doing this has an implication related to the schema that she had in her head regarding how this kind of lesson should be
enacted and thus, as was similarly noted in Sandy’s section, will need to be more thoroughly examined in chapter 5. The student’s reason for doing this is equally interesting and will be considered in the discussion on the interactions in Sarah’s lessons.

Sarah’s period 5B lesson was purposefully not mentioned in the preceding paragraph. A quick look at its SPM will make it quite clear that something different happened here. That SPM is a web of objects and lines connecting those objects which is representative of a very complicated process of idea exploration. What occurred in that lesson to make its activity structure so different from Sarah’s other three enactments, and how the exploration of ideas evolved into such a richly complex undertaking will require that special attention be given to the interactions in this lesson.

_Framing the Activity_

Comparatively speaking, Sarah devoted the least amount of attention to framing the activity of any of the teachers in this study, as represented by the very short time span of her Building Up the Problem segments (which were all around 90 seconds long). She did, though, supplement this minimal discourse-based orienting effort with the use of a student hand-out which provided some guidance through the activity. The hand-out had eight sections to it: (1) presentation of the equation and posing of the problem, (2) space for writing appropriate background knowledge, (3) space for writing background knowledge deemed relevant, (4) space for writing proposals and justifications, (5) space for writing “notes from the discussion that ensues as we test out different amounts of sulfur” (from the hand-out), (6) “An M&M Visual” (from the hand-out; an analogy to strengthen conceptual understanding), (7) space for writing notes about the formalized solution, and (8) “A Sparkler Reaction to Try On Your Own” (from the hand-out; an application also designed to strengthen conceptual understanding). It should be
noted that Sandy’s hand-out was much more content-oriented than the one used by Hannah which will be described in her *Framing the Activity* sub-section.

Perhaps because of the minimal amount of discourse-based attention she gave to framing the activity – and to discussing the nature of the empirical test – there was at least one instance of an exchange in which a student expressed uncertainty related to the purpose of the action within the activity (from her period 3 lesson):

181. Unknown male student: [Sarah], is that the ‘13 – 13’ [mixture]?
182. Sarah: No, this is the, um [pause] . . . this is the ‘6.4 and 13’ [mixture].
183. Unknown female student: And what is it supposed to be trying to show?
184. Sarah: Um, it’s supposed to . . . look like it would be a good propellant for a model rocket, so . . .

The other significant aspect of Sarah’s orienting approach to address is the variations in the placement and the extent of her discussion around the manner in which ideas were to be explored in this activity. Those variations are apparent in the following excerpts from her initial turn in three of Sarah’s four classes:

Sarah: Now, today, um, we’re going to take a look at this reaction [points to equation on overhead] between zinc and sulfur. And, it’s used a lot in model rockets. But instead of me just doing the demo for you and figuring out the amounts ahead of time, you guys are going to try to figure this out. So [interrupted by a student entering the room] . . . um, our problem today is, if I start out with ‘13 grams’ of zinc [points to this on transparency], how much sulfur do I use so that I get zinc sulfide? And if we do this correctly, we’ll get, um . . . a really good light show, okay. It’s a very good reaction – it gives off a light of heat, energy, and light, and it will be really cool if you do it correctly. (Period 1)

Vs.

Sarah: All right, this lesson today is going to go a little differently than, um . . . the lectures that you’re used to. Um, I’m going to present you with a problem, and it’s *your job* as a class to – well *we* our going to try to solve the problem together. Okay, so it’s not going to be ‘cut-and-dried’, ‘this is the right answer – this is the wrong answer’ type of thing. You have to *think* hard today. Um, this is the reaction we’re going to be looking at [reveals equation on an overhead transparency]. It is a reaction that is used in rocket fuel . . . model rocket systems.
Vs.

Sarah: Okay, let’s just get started here. The ‘lesson essential question’ is, ‘How can mass-mass stoichiometry be used to determine unknown amounts of reactants or products?’ This is the reaction that we’re going to be talking about today [pointing to equation on transparency]. It is often used in rocket – model rocket . . . um, systems, as a propulsion reaction. If done correctly, um, it gives off lots of heat and energy . . . um, it’s very exothermic . . . it gives off smoke. So, it’s a cool reaction if you do it properly; if you don’t do it properly, then it’s going to fizzle out and not be very nice to look at. (Period 7)

The reader will note that, in period 1, the process of idea exploration is given minimal consideration (“But instead of me . . . you guys are going to try . . .”); in period 3, that feature of the activity is made central to Sarah’s opening and given considerable attention; and, in period 7, this process is not addressed at all. In chapter 5 it will be valuable to reflect upon the implications of such differences in the way students were oriented to this aspect of the problem-solving activity for the way these MSP lessons unfolded.

The Nature of the Interactions

It was noted in the SPM sub-section that Sarah had a task segment unique to her lessons: Sharing Out Prior Knowledge. The discussion in this sub-section will begin by examining an important feature of the interactions in this segment – a feature which can be ascertained by comparing the following excerpts from three consecutive sequences all occurring later in this segment during Sarah’s period 5B class:

Sequence 12

128. Sarah [picking up the hand-out she is using with students]: Okay, um, ‘Which pieces of information do you think would be important for solving this problem?’

129. Unknown male student: Exothermic [1st point suggested].


131. Unknown female student: Hunt-uh [no].
132. [A couple of seconds of silence, then . . .]

133. Same female student as 131: No [definitively].

134. Sarah: No. Okay, I’m markin’ it off then
   [she does this].

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Sequence 13

135. Sarah: ‘Composition / Synthesis’ – is that important
   for determining the amount of sulfur?

136. [About 3 seconds of indeterminate noises.]  

137. FS 5: No.

138. Sarah: How come?

139. FS 5: Um . . . because . . . well, I don’t know – it’s getting . . .

[There are another thirteen lines in this sequence involving moves similar to the ones present in
this partial excerpt.]

Sequence 14

153. Sarah: The fact that it’s ‘redox’ – how about that one?

154. Unknown male student: Yeah!

155. FS 5: Yeah, sure.

156. Unknown female student: Yes.

157. Sarah: That’s an important part of the reaction, but do
   you think it’s important when we’re trying to figure out
   ‘grams of sulfur’?

158. FS 5: No.

159. Sarah: Okay [shaking her head]. I would argue ‘No’ [it’s not
   useful] as well. [Crosses out this contribution]

This portion of the Sharing Out Prior Knowledge segment serves as a vetting process to
determine which of the ideas offered earlier in the segment will be most useful in solving the
problem, a goal that Sarah lays out in line 128. Of greatest interest here are the differences in the
interactions through which that vetting process is accomplished in the three sequences. In the
first one, the female student’s assertion that the exothermic nature of the reaction will not be
useful in helping to solve this problem is accepted at face value by Sarah. In sequence 13, FS 5 makes a similar assertion regarding the fact that it is a synthesis/composition reaction, but it is not taken at face value: Sarah makes a request for justification related to that assertion (and the lines which were not included from this sequence contain similar requests of other students who support this assertion). Finally, in sequence 14, after three different students (in lines 154–156) indicate that they think knowing it is a redox reaction is a useful piece of information, Sarah herself refutes this evaluation, makes a second request for evaluation, gets the desired response from FS 5 (who has changed her evaluation from line 155), and then shows support for it.

The inconsistency of Sarah’s use of a request justification move in the dependent exchanges in the Sharing Out Prior Knowledge segment was even more significant in her other two classes: In her period 1 class, Sarah never made a request for justification in this segment, and in her period 3 class she always made such a request. Further, there were other instances that paralleled what happened in sequence 14 where Sarah seemed to be making additional requests for justification until she got the answer that she wanted (e.g. sequence 13 in period 7).

Once the action moved on to the Proposing Solutions segments, there was a feature of the interactions which connects Sarah’s lessons to Sandy’s. This feature is represented in the following three excerpts each of which occurred at the beginning of this segment in their respective class (periods 1, 3, and 7):

From period 1:

65. Sarah: Okay. Um, some people are getting some really good things and I wanna get these down, so let’s talk through some of them. [Several second pause while she sets up for this.] I’m just going to re-write the reaction here: Zinc and sulfur goes to zinc sulfide. [Writes on transparency] And we’ve got ‘13 grams’ [of zinc]. [Writes on transparency] Okay, so, um, let’s see [pause] . . . [MS 3], you had some good stuff written. What did you have?

66. MS 3 [14:02]: Uh, ‘zinc equals 13 grams.’
[*This is really setting the stage for the true ‘Give I/P’ which occurs in line 131.]

67. Sarah: Okay, so we’re starting out with ‘13 grams.’ Right. ‘13 grams of zinc’ [writes on transparency as she says it].

   What did you do with that?  

68. MS 3: Uh, well then I put it’s equal to . . . Um, one mole of zinc equals ‘65.38 grams’.


[And then, after a couple of sequences spent going through the steps of the calculation started by MS 3 ...]

130. Sarah: Okay. Which I think is what [FS 5] was trying to get to.

   So, in ‘one mole’ of sulfur, there’s ‘32 grams’. [Writes this on transparency] And ‘.2’ times ‘32’ turns out to be ‘6.4’.

   [Writes out this calculation]

   So my mixture should – theoretically – be what? ‘13 grams [of zinc]’ and . . .

131. Unknown male student: ‘6.4’.

   From period 3:

130. Sarah: I’d really like to show you this demo, but we’ve got to talk through it first. Um, possible solutions and why. [MS 12].

131. MS 12: Um . . . ‘6.4 grams’.

132. Sarah: Okay, um, you gotta tell me how you got that.

133. MS 12: Uh . . .

134. Sarah [to rest of class]: Sshh! Guys – listen!

135. MS 12: Basically, I took the . . . the amount of zinc that we used . . .


137. MS 12: ‘13 grams’ . . .

   And divided it by the molar mass . . . [Cont. Dep.—R, Give C / E from 135]

138. Sarah: Which is?

139. MS 12: ‘65 [grams]’.

[This is followed by 10 more turns in which MS 12 runs through the calculation he used, and]
then this sequence ends with the following exchange . . .]

150. Sarah: And that gives you how many grams?

151. MS 12: ‘6.4’.

152. Sarah [while putting cap on overhead marker]: All right, let’s . . .

[Instead of finishing her thought from line 152, Sarah initiates a new sequence; the first exchange in that sequence will be presented . . .]

153. Sarah [continuing from 152]: . . . Uh, well, do people agree with this?


155. Unknown male student: I did that.

156. Another unknown male student: Mine’s different.

[*Based on the limited responses, it is not clear whether the idea or the reasoning is being supported / refuted.]

157. Sarah [to student from 156]: Yours came out differently . . .

[After 13 more turns, it is determined that the male student from 156 had just made a mistake in his calculation. This, then, led to the final pair of exchanges that will be given in this excerpt, which began a new sequence . . .]

171. Sarah [continuing from 170]: Um, do you suggest we try ‘6.4 grams’ of sulfur, or is there another solution that’s that’s out there that you guys want to test?


173. Sarah [ignoring this proposal]: How many people want to try ‘6.4’?

174. [No apparent response]

From period 7:

111. Sarah: Okay. I see some people doing some calculations [2 sec. pause as she walks up front] . . . Soo, um, anybody want to tell me what they’re doing? [2 seconds pause] [MS 6].

112. MS 6: Can I give you the answer?

113. Sarah: Umm . . . okay, go ahead and give me the answer.

114. MS 6: ‘6.37’.

115. Sarah: ‘6.37 grams of sulfur’ [writes this down].
[Looks at MS 6]
116. MS 6: Yep.

[Sarah begins a new sequence . . .]

117. Sarah: Did anyone come up with a different value? [MS 3].
118. MS 3: ‘6.412’.
119. Sarah: [Writes this down] Okay, so we’re still around ‘6.4’.
   [1 second pause] Um, any other suggestions?
120. [No response.]

[The, following the lack of response in line 120, Sarah begins another sequence with the last exchange that is relevant to the point being made . . .]

121. Sarah [14:32; 3 seconds after previous turn]: Okay, I wanna know how you guys got ‘6.4 grams’. [MS 7].
122. MS 7: Um, you take the ‘13 grams’ of zinc [pause as Sarah is writing this down in a calculation] . . . and divide it by the molar mass of zinc to find out how many moles there are.

It will be helpful to cull the main point from the three pages of transcript that have just been presented by summarizing key details, and the reader can refer back to each excerpt as this summary proceeds. The discussion will focus on the sequence in which certain discourse moves and interactions took place.

In period 1, MS 3 begins what ultimately becomes the first proposal by setting up the opening action in the calculation he performed – and not actually presenting the value for this proposal. This initiates a series of exchanges which run through two [long] sequences in which the steps of the calculation are explicated by several students in the class (including MS 3). Finally, at the end of the second sequence (in line 131), a male student offers the value that corresponds to the actual proposal. In the subsequent sequence (not presented), there is no request for evaluation of this proposal nor is there a request for alternative proposals; Sarah simply asks the students to predict the results of testing the proposal.
In the period 3 excerpt, the situation immediately starts off differently as MS 12 gives the value representing his proposal right away (line 131). This is followed by a request for elaboration by Sarah (which suggests a second point to be made below) and that request leads to the explication of the calculation which produced MS 12’s value. At the end of this explication, after MS 12 has repeated the value (line 151), Sarah is just about to say something when she stops herself and makes a request for evaluation. Most students show support for MS 12’s idea, and it is eventually determined through this sequence that the one student who didn’t initially agree had made a mistake in his calculation. With this issue resolved, Sarah begins the last sequence of relevance with a request for alternatives.

In the period 7 excerpt, events begin in a similar fashion to period 3 as MS 6 gives a value corresponding to his proposal in line 114. However, that is where the similarities end as Sarah begins the next sequence with a request for alternatives before any further discussion of MS 6’s idea takes place. After an initial alternative is deemed to not be different enough from MS 6’s proposal and there is no response to a second request, Sarah returns to MS 6’s idea and makes a request for elaboration.

The point which has been developed, then, is that – like Sandy – Sarah exhibited inconsistency in the way she sequenced critical initiation moves in the Proposing Solutions segment. In period 1, the student’s proposal was followed by a series of requests for elaboration and there was never a request for evaluation or a request for alternatives; in period 3, the student’s proposal was followed by a request for elaboration, then a request for evaluation, and finally a request for alternatives; in period 7, the student’s proposal was followed by a request for alternatives before a request for elaboration was made (and there is never a Req. Eval.).

While there was no data from Sandy’s class to indicate the significance of her
inconsistent use and sequencing of the key dependent-exchange initiation moves, there is at least one event from Sandy’s class which speaks to this issue. It occurred in her period 1 class in a sequence found just after the test of the first proposal had been completed (and this proposal had been shown to be tenable):

178. MS 13: Let’s try adding ‘13 grams’ [of sulfur].
179. Sarah: Oh, you want to do ‘13’ and ‘13’?

[*This was probably not meant to be a Req. Just. for why this proposal should be tested, but it was treated as such by the unknown male student in the line that follows.]

180. Unknown male student: Yeah since that was one of our theories.
181. Sarah: Okay, that’s actually a very good suggestion. Let’s go ahead and try that.

The line on which to focus in this sequence is the male student’s utterance in line 180. He recognizes MS 13’s proposal as “one of our theories” – indicating that this idea had been considered by at least a few members of the class – and yet nowhere prior to this point in the transcript was this proposal brought up. What this means is that this idea was produced by students during the Idea Generation segment but was not shared out with the rest of the class in the Proposing Solutions segment. This is likely the result of the lack of a request for alternatives move by Sarah following the initial proposal; it is possible, however, that even if such a move had been employed, if it followed a lengthy set of exchanges stemming from a request for clarification / elaboration move (particularly where a complicated calculation were laid out), students would be less likely to offer such alternatives.

There is a final point to be addressed before leaving this set of excerpts. After a lengthy discussion related to this point, the researcher and co-coder agreed that there was something different happening within the dependent exchanges subsequent to proposals in Sarah’s classes
than in the classes of the other three teachers doing this lesson. Whereas the other three teachers usually included an initiation move which represented – based both on the language used and the goals explicitly stated by the teacher – a request for justification, Sarah replaced this with a move more indicative of request for elaboration. Beyond the fact that Sarah’s implicit goal in the Proposing Solutions segment seemed to be more about having students show proficiency in conducting certain calculations than anything else, the language she employed supports this distinction (see for instance line 132 in the period 3 excerpt and line 121 in the period 7 excerpt).

There is one other interaction related to the way ideas were explored to discuss – an interaction that supports the mutual understanding commitment and is a result of a discourse move only found in Sarah’s and Hannah’s transcripts. The example of this interaction comes from her period 1 class and occurs after MS 3 and FS 1 have begun working through the calculation that will eventually generate the value for the first proposal. Sarah interrupts this process to engage in the following exchange with FS 10:

90. Sarah: Um, let’s see [pause] . . . [FS 10]. Why do you think she did that [referring to a step in FS 1’s calculation]?

91. FS 10: Um, because [several second pause] . . . yeah, because she’s a genius [responding to a prompt from another student]!

92. [Students laugh]

93. FS 10: No, because you have to, like, multiply them together to get ‘ZnS.’

94. Sarah: Okay.

95. FS 10: I don’t really know how to explain it. Like, I understand why she did it, I just don’t know how to explain it.

96. Sarah: Okay.

The request for re-explanation move (found in line 90) has the potential to support mutual understanding by insuring that other participants in the class are versed enough in the proposal made by a particular individual to discuss it and evaluate its merits. While it is likely that
Sandy’s use of this move in the excerpt above (and later in this same sequence) was a result of her focus on checking students’ proficiency in performing certain calculations, interactions like this still have value in terms of progressing the discourse. It will therefore be worthwhile to compare the way in which Sarah used this move to the manner in which Hannah utilized it.

Moving on to the interactions which occurred around the testing of ideas, there is a pair of sequences to consider from Sandy’s period 1 class. Both sequences took place after the equal-mass proposal had been tested – and this proposal had been suggested after the stoichiometric-mass mixture had already been tested (as was shown two excerpts back). Thus, the participants have both test results in their background as they engage in these interactions:

**Sequence 33**

189. Sarah [27:37]: All right. So this is an equal mass amount with ‘13 grams’ and ‘13 grams’. Let’s see if we get the same results. [Monologic]

190. [Sarah conducts the test between 28:50 and 29:13. The following student comments can be discerned right at the end of / immediately following this testing phase . . .]

   b. Another male student: Yeah. [Nuc. – F to statement in a.]
   f. Unknown female student: That was awesome! Nuc. R* **Give Ana. Res.**

[*Coded as such based on the practice of treating the test itself as the initiation move.]

**Sequence 34**

191. Sarah: All right. My question . . . That – that did, you know, pretty good . . .

192. Unknown male student: Why did it work better? Att. I

193. Sarah: Um, which one do you think [interrupted by flare-up of reaction . . . would be better for rocket fuel –
something that . . .?

194. Unknown female student: That one [referring to 2nd mixture].

195. Sarah: This one?

[*This is said in a manner that indicates Sarah is questioning this evaluation.]

196. Several [mostly male] students: No, the first one.

197. [A couple of seconds of debate occurs. Some of the comments that could be pulled out of that debate are as follows . . .]

   a. Unknown female student [29:26]: The first one was more consistent.

   b. Unknown male student [29:28]: The second one was slow burning.

198. Sarah: Right. So even though this amount did burn [interrupted by another flare up] . . .

199. Unknown male student: It’s still burning.

201. Sarah: . . . the first one would probably be best. [Cont. Nuc. – F from 199; Supp. Reas.]

An important feature of this set of interactions is the extent to which Sarah is active in the analysis of the results and influences the outcome of that analysis. Even though several of the statements from students in line 190 indicate that they felt the equal-mass mixture had produced a more impressive result than the stoichiometric-mass mixture, Sarah began sequence 34 by downplaying this result by saying, “that did, you know, pretty good.” Further, she showed no uptake of the student’s question in line 192, and then, when a student suggested that the equal-mass mixture would be better as a rocket fuel, Sarah questioned this analysis. Sarah’s involvement in this manner changed the form that the interactions took in this portion of the activity – and impacted the extent to which the empirical testability commitment was upheld.

Giving One Lesson Special Consideration

As was the case with the discussion in the SPM sub-section, the way that events unfolded in Sarah’s period 5B class warranted a separate treatment of the nature of the interactions within
it. Because of the complexity of these interactions and the extent to which events in earlier task segments and sequences laid the foundation for events in later ones, it will be necessary to trace two different lines of reasoning which were tightly interwoven through a set of excerpts. After each excerpt, crucial interactions will be highlighted and analyzed, and their connections to future events will be indicated.

One of the things which makes this lesson so interesting is the unimpressive seed from which this intricate tangle of interactions issued forth: an ambiguous contribution to the Sharing Out Prior Knowledge discussion which became an object of debate. The sequence in which that seed was planted begins this set of excerpts:

Sequence 11

90. MS 3: Uh, it’s one-to-one.  Nuc.  R  Give I / P
92. MS 3: Well, [FS 2] said it, so I thought it sounded good.  Emb.  R*
[*MS 3 wasn’t really answering Sarah’s question, he was defending his proposal of this idea.
Sarah’s question is still coded as Req. C / E because the student in line 93 treats it as such.]

93. Unknown male student: <There’s a one-to-one ratio.  Dep.  R  Give C / E
95. Same unknown male student: Like, Zn [zinc] <<to sulfur.  Att.  R  Give C / E
96. FS 5: <<Well, masses.  Dep.  R  Give C / E
98. MS 5: <<<<Molar masses.  Dep.  F**  Give C / E
[**Because of the timing of this, it seems that MS 3 is trying to clarify what FS 5 meant, although as becomes clear later, she was not referring to molar masses, but to regular masses.]

[***Coded as this because the student is both refuting FS 5’s Give C / E and responding to Sarah’s Req. C / E.]

100. MS 5: <<<<Molar ratio.  Dep.  R  Give C / E
101. Sarah: Well which is it?
102. Same unknown female student: *Moles.*

103. FS 5 [2 sec. after the line 102 utterance]: *Grams.*

[****These (lines 102 and 103) are evidence that FS 5 meant something different than the unknown female student and MS 5.]

104. Same unknown female student as 102

[responding to FS 5’s utterance]: No!

105. Sarah: One-to-one ratio of . . . grams? [Writes this on transparency]

. . . moles? [Writes this on transparency] What is it?

106. Unknown male student: Oh, we didn’t get through the whole . . .

[*He is referring to a note packet in which Sarah introduced students to the mole and the different ways of interpreting coefficients in a chemical equation.]

107. FS 5: *Mass.*

108. [There are a couple of seconds of silence.]

109. Sarah: Well, it’s one-to-one of *something.*

We know there are . . . coefficients here and they’re all ‘1’.


123. Unknown female student: <Yeah, we need to finish the packet.

[**This is a response to an utterance from the omitted section.]

124. Sarah: Okay, ‘grams’ is your final answer. We’ll go ahead with that, *but* [emphasized], um, it might [stops herself] . . . Yeah, we’ll just go ahead – we’ll go ahead with that. Sure.

Unintentionally, MS 3’s proposal in line 90 and the male student’s attempt to clarify it in line 93 – because they are both ambiguous as to their meaning – begin a debate over the interpretation of the coefficients in the balanced equation for this reaction. On the one side of this debate are FS 5 and at least one male student (from line 122) who have [incorrectly] construed them to mean ratios of masses; on the other side are MS 5 and the female student from lines 99, etc. who have [correctly] interpreted them to represent ratios of moles. A very
important aspect of this initial dispute is that, in several key places (lines 101, 105, and 109), Sarah keeps this debate open. Further, in line 124, she allows it to be temporarily resolved – but in such a way as to express a level of uncertainty in this acceptance. While one can argue about the pedagogical validity of allowing this extended back-and-forth arguing of opinions without requiring any warrants to back those opinions, the fact that this debate was left open becomes crucial to all that transpires in the subsequent excerpts.

The second extract is taken from the beginning of the Generating Solutions segment:

169. Sarah: Okay, if you guys said something about a ‘one-to-one ratio’ [writes this down on new transparency] . . . we weren’t really sure what it was – was – either grams or moles – it’s something – um, suggest how much sulfur to use if we start out with ‘13 grams’ of zinc. So go ahead and write down a solution, be able to explain why you think it is that, and then we’ll talk about it.

170. [A couple of seconds elapse.]

171. FS 5 [barely audible]: What solution?

172. Sarah [11:10]: What’s your question?

173. FS 5: Well . . .

174. Unknown female student: Are we try- . . . Are we gonna see, like, if it’s like mass (inaudible) or what?

175. Sarah: Um, one way to think about this is we’re trying to see one-to-one mass ratio or a one-to-one . . . whatever [looks at transparency] . . . we had said . . . <we had said . . . moles . . . or molecules.

176. Unknown male student: <Molecules.

[*This is coded as such because in making his utterance in 176, the unknown male student is treating this as if Sarah is looking for some help in remembering how they labeled the 2nd interpretation of the coefficients.]

The most critical aspect of this second excerpt is that Sarah takes advantage of the open state in which the earlier debate was left to re-formulate the problem at the heart of this activity
Instead of the problem being generally about what mass of sulfur is needed to react with the given amount of zinc, it is now specifically about which of two solutions—based on the different interpretations of the coefficients—is most valid. This re-formulation represents a Jamesian happening (Woods, 2003, as discussed in the Literature Review) and will allow two genuinely different student proposals to emerge in a later excerpt.

The third extract occurred at the very beginning of the Proposing Solutions segment:

190. Sarah: All right. Um, [FS 5], what do you got? Nuc. I Req. I / P
192. Sarah [to rest of class]: Shh! Emb. I
193. FS 5: . . . really . . . don’t have anything. Nuc. R Un. Meet Req.
195. FS 5: I don’t have a calculator, but . . . Dep. I Give Info.

The reason this excerpt is included is because, instead of opening this segment up by allowing students to volunteer proposals (as in her other classes), Sarah specifically calls on FS 5, perhaps because she was the main proponent of the mass-ratio interpretation of the coefficients. It is also included because FS 5 indicates that she has no proposal at this time—significant in light of events that will transpire in the next excerpt. A final point to make is the fact that FS 5 blames this lack of a proposal on the fact that she doesn’t have a calculator, indicating at least that she is aware that one possible route to a solution is through a formal calculation.

The fourth extract is where the two different proposals start to crystallize. It has been drawn from a point part way through the sequence following the one in which excerpt 3 took place. Up to this juncture in the sequence, Sarah has taken the kernel of a proposal by FS 9 and started to guide students through the process of turning it into a formal solution. At the point at which this excerpt picks up, Sarah asks a fundamental question about one of the steps in the
calculation underlying this process:

216. Sarah: ‘.198’. Okay, let’s round to ‘.2’ [writes this on transp.].
Where does this get us, though?

217. Unknown male student: Um, maybe we need the same . . . like
we need to get one mole of, uh . . . uh, sulfur.

218. Sarah: Um, *one mole* of sulfur? You’re suggesting one mole of
sulfur too? We have <‘.2 moles’ . . .

219. Same male student as 217: <Oh, no wait – we need ‘.2’ moles
of <sulfur.

220. FS 5: <<Wait, doesn’t that have to be even on both <<<sides?

221. FS 9: <<<So you would have to convert moles to grams.

222. FS 5: Doesn’t that have to be even <<<on both sides?     Dep. I Seek. Under. Quest.

223. Sarah [towards FS 9]: <<<Okay.
[towards FS 5] ‘Does it have to be even on both sides?’ –
what do you me- . . .?

[***This part of the turn is a response to FS 9’s utterance in line 221 and ****this part of the
turn is a response to FS 5’s question in line 220 (and line 222).]

224. FS 5: Both sides of the arrow [yields sign].

225. [A few seconds of silence while Amber writes something on the transparency. It is not
clear whether what she writes is related to the question being asked by FS 5 or the
calculation being suggested by FS 9.]

226. FS 9: So now we have to find <<<the molar mass of zinc
and sulfur.    [Cont. Dep. – I from 221; Give C / E]

227. FS 5: <<<So does it have to be same mass on both sides?    Dep. I Seek. Under. Quest.

So if we find the molar mass of ‘ZnS’, you can subtract . . .

228. Sarah: Well, the thing is we don’t have the ending mass of zinc
sulfide yet.

229. FS 5: Can’t you just look on the thing [periodic table]?

230. Sarah: I mean, we . . . <if we start out with ‘13 grams’ of zinc
[pause] . . .

231. <[There is an inaudible exchange between a male student and FS 5
while Sarah is continuing her refutation.]

Do we know?  

Dep.  I  Req. Info.

233. FS 5:  No.  [Stated reluctantly indicating she knows her solution isn’t going to work.]  


At the beginning of this excerpt, the dialogue is efficiently moving along through the reasoning which will eventually lead to the stoichiometric-mass proposal. In the midst of this (line 220), FS 5 has an insight (indicated by the discourse marker Wait) that leads her to pose a question which is not initially taken up. Undaunted, FS 5 repeats the question in line 222. It is at this point that a unique interaction takes place (occurring in this data corpus only here and in the next excerpt): In line 223, Sandy both provides a follow-up to FS 9’s utterance from line 221 – which continues to progress the conversation towards the creation of the stoichiometric-mass proposal – and initiates an exchange with FS 5 in recognition of the question she has asked – an exchange which contributes to FS 5’s movement towards the equal-mass proposal. In other words, in a single turn Sarah has simultaneously engaged two different participants in two different conversations which eventually will lead to two different proposals. These twin conversations are maintained through two more turns (lines 224 and 226) before Sarah begins a pair of exchanges with FS 5 which indicate a flaw in FS 5’s current line of reasoning.

For the next 16 turns, the discourse returns to a focus on working through the calculations which lead to the stoichiometric-mass proposal. Just as the class is approaching the final step in that calculation – and the actual value corresponding to this proposal – Sarah asks a question intended to bring closure on the earlier debate over the meaning of the coefficients. While it is clear that it has this intended effect on some of the students (see line 251 below), it also has an unintended effect on FS 5 – finally allowing her equal-mass proposal based on the [incorrect] interpretation of the coefficients as mass ratios to crystallize:
249. Sarah: Um . . . So, implicit in what you guys just said is that
these coefficients . . . are moles. Is that right? Number of moles?
. . . As opposed to number of grams?

Dep. I Req. C / E

250. Unknown female student: <What’s one-to-one?

[*It is not at all clear to whom or what this question is directed.]

Att. I*

251. A couple of students: Yes.

Dep. R Give C / E

252. FS 5: <Isn’t that the number of atoms?

Dep. I Req. C / E**

253. Sarah: Okay <let’s go ahead and try that.

Um [1 sec. pause] . . . yes, it is also number of atoms – we talked
about that being ‘number of atoms’ also. Mmhh. But we can’t
go and pick out one atom of zinc – it’s just too tiny. Right?

Dep. F Accept.**

[**Sarah was just about to move into the testing of the proposal based on the stoichiometric
mixture; however FS 5’s question interrupts that action.]

254. FS 5: So wouldn’t it be ‘13’, ‘13’, ‘13’ [.13 grams’ of each reactant
should be combined and would give 13 grams of product]?

Dep. I Give I / P***

[***This is the point at which the equal-mass idea is officially offered and recognized.]


Dep. R Accept.****

[Writes this on transparency]

Reify Contr.

[****Sarah’s interrogative intonation indicates she is questioning this idea but FS 5 does not
interpret it as such and Sarah does not push her further about it at this point.]

256. FS 5: And then ‘26’ on the right [product side].

Dep. F Give C / E****

[****This is hard to figure out. In 254, the third ‘13’ should refer to the mass of the product
and Sarah writes it down as such initially. Yet in this statement, FS 5 indicates that there
would be ‘26 g’ of product and Sarah writes it in a different position on the same side of
the equation as the ‘13’. There seems to be some confusion about what FS 5 means but
Sarah never asks her to clear it up.]

257. Unknown male student: I bet it’s not.

Dep. I Ref. I / P

258. FS 5 [said with slight laugh]: Yeah, I know.

Dep. R Accept.

259. Sarah: Okay . . . <um, we . . .

Att. I

260. FS 5 [Re-thinking response from line 258]: <Yeah it is because

Dep. I Sup. I / P

261. Sarah [after 2 second pause from line 260]: <<We’re <<<going
to try that [referring to FS 5’s ‘equal mass’ idea].

Att. I

262. Same male student as 257 [seeing FS 5’s logic]: <<<Ah, so it is.  Dep. R Show Agree.*
[This is a response to FS 5’s defense of her idea in line 260.]

Sarah’s turn in line 253 represents the second example in which she engages in two different conversations related to the two different lines of reasoning simultaneously. Interestingly, the part of this turn directed towards FS 5 is intended to point out a flaw in her thinking; instead, in the ensuing turn, FS 5 officially presents the equal-mass proposal. What is intriguing about this situation is that, when one looks back at excerpt 3 and recalls that FS 5 initially was unable to provide a proposal, it becomes apparent that this idea emerged from the conversation taking place within this segment. The remaining lines of this extract involve the reification of this proposal by Sandy and FS 5 defending it against a minor criticism from a male student.

The last excerpt in this set takes place just a couple of turns after the previous one ended. Sandy had expressed her intent to test out FS 5’s idea, but only after the line of reasoning related to the stoichiometric-mass proposal is completed. Just as she is about to restart that dialogue, the following event takes place:

265. [FS 2 has her hand raised.]

266. Sarah: [FS 2].

267. FS 2: But if . . . if you use like, um, just grams and stuff like that, wouldn’t there be more molecules of one element than the other and then the reaction <wouldn’t take off probably.

268. Sarah [who begins shaking her head in affirmation just after FS 2 says “one element”]: <Yeah, um [a second or two pause which allows FS 2 to finish her turn in line 267] . . . How do you know that?

[*That this is what Sarah is looking for here is supported by her re-formulation of the question in line 270.]

269. FS 2: What do you mean?

270. Sarah: How do you . . . how would you figure that out?

271. FS 2: Well because . . .
272. Sarah: I’m not saying your wrong . . . <I’m just saying . . .

273. FS 2:  <No,
well . . . if you have one mole of zinc and one mole of sulfur,
and their molar mass is different, then . . .

[**This is finally FS 2’s response to the intended question Sarah asked in line 268.**]

274. Sarah:  Okay, yes. So because their molar masses are different, it’s just like if you have [pause while she looks for her cups of M&Ms] . . .

When Sarah accepted FS 5’s proposal for testing in the previous excerpt, she made no request for evaluation of FS 5’s ideas. Nonetheless, FS 2 felt compelled to provide such an evaluation, and did so in the form of the most sophisticated critique of a proposal found in this corpus of data (in line 267, and then continued in line 273). To formulate this critique, FS 2 had to both consider the implications of FS 5’s proposal as well as synthesize disparate bits of information related to the meaning of the coefficients and the relative masses of zinc and sulfur.

What occurs after this last excerpt is that Sarah builds off of FS 2’s criticism by bringing in an M&M analogy (which, as will be discussed in the next sub-section, was part of the Formalizing the Solution segment in the other three classes) to provide a concrete representation of what FS 2 was describing. The combination of FS 2’s criticism and the M&M analogy effectively invalidate the reasoning behind the equal-mass proposal and remove it from contention as a viable solution before the testing phase. (In a vote related to which idea students thought would produce a better result prior to the testing phase, no one – not even the outspoken FS 5 who offered it – selected this choice.)

To summarize the discussion over the last several pages, through the confluence of an intriguing set of circumstances (an ambiguous contribution from a student, Sarah’s willingness at times to let a debate remain open, and FS 5’s outspoken nature), the exploration of ideas in Sarah’s period 5B lesson unfolded in a unique way (compared to other lessons in this corpus)
and produced some unusual interactions (again, relative to the larger corpus). The significance of this as it relates to the notion of an ‘ideal’ MSP structure will be considered in chapter 5.

**Formalizing the Solution**

Much as was the case in Sandy’s lessons, in each of Sarah’s lessons there were two proposals tested: an equal mass of sulfur and a stoichiometric mass of sulfur (i.e. the accepted solution). As was discussed in the SPM sub-section, in two of Sarah’s classes, she was the person to make the equal-mass proposal. In her post-lesson interview (3), Sarah explained that this was done to eliminate misconceptions related to interpreting the coefficients in the equation in terms of reactant masses by showing that this interpretation produced an untenable solution.

Based on what was said in the preceding paragraph, one would guess that Sarah would have been very explicit about connecting the accepted scientific explanation to both the tenable (stoichiometric) and untenable (equal-mass) solutions – and, indeed she was. That fact represents another parallel between her set of lessons and Sandy’s set. However, there was a difference between the two in the way those connections were drawn out through the discourse – a difference which one can ascertain by comparing the excerpt below (from Sarah’s period 3 lesson) to the one found in Sandy’s FtS discussion:

215. Sarah [23:21]: So I want you to tell me why *this one* [with ‘6.4 grams of sulfur] was *good* and *this one* [with ‘13 grams’ of sulfur] was *bad*. Why was the ‘13 grams’ and ‘13 grams’ *bad*?

216. Unknown male student: Because the second one was (inaudible).

217. Sarah: Well, you need to tell me *why* – that’s not a good explanation.

218. MS 14: Because they weren’t balanced. [Sarah does not seem to hear this.]

219. Sarah: [FS 5].

220. FS 5: Because the second one, um, the ratios were correct. And in the first one, they aren’t.

221. Sarah: Ratios of ...?

222. FS 5: Of like ... of the grams [voice trails off]. Like, if you convert them back
to the moles, then they . . . then it’s the right ratio [said more confidently].

223. Sarah: All right. So, ‘correct mole ratio’ [summarizing what FS 5 has said by writing this on the transparency].

As opposed to Sandy’s approach to this, in which she did the majority of the explaining and merely allowed students to fill in answers to slotted questions, Sarah put more of the onus of providing the explanation on the students. And she is not looking for an explanation that’s ‘in the ballpark’ – as her follow-up to the male student’s utterance in line 217 and request for elaboration from FS 5 in line 221 indicate; she is looking for an answer which captures the central points developed during the exploration of ideas.

One other feature of Sarah’s FtS warrants mention: In three of the four classes (periods 1, 3, and 7), after sequences such as the one above in which she gave students the opportunity to use the scientific explanation to account for the differing results between the equal-mass and stoichiometric-mass proposals, Sarah used an analogy involving plain and peanut M&Ms to help students further visualize how the scientific explanation accounts for these differences at the atomic level. The reason for mentioning this is that, in Sarah’s period 5B class – the one in which a true debate between alternative ideas arose – this analogy was moved up into the Proposing Solutions segment and effectively brought an end to that debate prior to the actual testing of the two different proposals (something briefly discussed in the preceding sub-section).

Nancy’s Lessons

A Sketch of Nancy

Nancy had the least amount of association with the researcher of any of the participants other than Marty: Nancy had applied to take a temporary position made available when the researcher took a leave of absence several years prior to the study and the researcher had come to know her through the interview process. Through a bit of serendipity, the two were re-
acquainted just as the researcher was beginning to enlist participants for this study. Nancy was a good candidate because she had an amount of teaching experience intermediate between Sarah’s / Hannah’s and Sandy’s (and similar to Marty’s). One thing which set her apart from the other individuals involved is that she had just completed a PhD program in educational psychology at a nearby university prior to the beginning of the data collection.

Because of the small size of the school in which she taught (discussed above), Nancy was responsible for the greatest number of different class preparations of any of these teachers: five (physical science, ‘regular’ chemistry, ‘accelerated’ chemistry, advanced chemistry, and physics). Although limiting her ability to design and implement what she described as ‘pure’ inquiry activities (interview 1), this course load offered an opportunity not available with any of the other participants (except Marty): to conduct this lesson with two different ‘ability levels’ of students – the ‘lower ability’ regular chemistry class and the ‘higher ability’ accelerated class.

Given that Nancy had covered very similar content in the two classes throughout the year (just going into more depth with some of it in the accelerated class) and that both sections were ready to begin the same unit, this was a distinct possibility. Nonetheless, Nancy did express a certain reluctance about conducting the MSP lesson in classes with these differences in academic ability – a reluctance related to having ‘wrong ideas’ put out there during the course of such a lesson:

Um, I would have more reservations with a middle or lower student than I would with a higher student. I think the higher student can take that [wrong ideas] and use it, um, and the gifted students should actually be made to do that. I think that’s . . . I think it’s a skill that they should be able to do. But, I’m thinking that the middle and lower students are more . . . The ones that I see tend to take what you say as the ‘gospel’ truth. (Interview 1, section C.2)

Despite this reservation, Nancy saw enough value in the experience offered by the MSP structure to agree to teach the Zn-S lesson to both levels of her introductory chemistry course. Interestingly, she also expressed a concern connected with conducting this lesson in her
accelerated class – this one specifically tied to the kinds of interactions which might arise:

I want them to think what *they* think. And I do have trouble with that class [accelerated chemistry] getting them to that *independent* thought. I mean, they just would rather . . . you know, whoever comes up with the first idea, they’ll just kind of roll with it. So, that’s what I’m trying to do – is get them to all come up with an idea first and then, you know, go from there. (Interview 3, section B.4)

Thus, structuring the activity in this lesson in a manner which insured that each student had the chance to develop and explore their own ideas was a major concern that drove Nancy’s approach to this lesson – in both classes. As will be seen, this had an impact on a number of interactions which occurred in both classes during the segments where proposals were being offered and evaluated by the students.

The other objective that influenced Nancy’s practices within her enactments was her emphasis on justification, which comes through in this exchange which followed the researcher’s question about what meaningful dialogue represents to Nancy (interview 3, section B.3):


Researcher: Yeah.

Nancy: Yeah. Um, yeah, I think the . . . the reasoning of it . . . It’s easy just to come up with an answer, but I want them to reason through it and know *why* they came up with that answer – think about *how* they had come up with that answer. I know I had talked before about the whole metacognitive thing about their thinking and trying to get them to think, ‘Okay, where am I going with this? Why am I going this way?’ You know, ‘Am I going in the right direction?’ For them, they don’t . . . Not all of them are comfortable with that. You know, they’re more . . . they just want to be right as opposed to, you know, trying to find the right path.

It will be important, then, to keep in mind these two influences as the data describing the interactions in her classroom are examined to contemplate the extent to which there are traces of these influences discernible in those interactions.

*Solution Pathway Maps*

Up to a certain point, the SPMs for Nancy’s two lessons show tremendous similarity to
those for Sandy’s and Sarah’s lessons – all the way up through the first Analyzing the Test segment in fact. The similarities for those beginning portions of the lessons run even deeper when one compares Nancy’s two lessons to Sandy’s period 1 and 3 lessons: In both cases, after the problem is posed, the same initial solution is offered in all four cases (6.54 grams – equal mass), no other alternatives are considered (a point to be addressed further in the Interactions sub-section), and this solution is tested and determined to be untenable.

However, the parallels between these two sets of lessons (Nancy’s and Sarah’s) are interrupted by what comes next in each case. As was discussed in the section on Sandy’s SPMs, the segment following the analysis of the first test is initiated in all three of her lessons by a turn in which she asks students to consider why the first proposal didn’t work; this set a goal of trying to find the flaw in the logic which led to that proposal. By comparison, the segment following the analysis of the first test in each of Nancy’s two classes was initiated with an utterance represented by this turn from period 3:

210. Nancy: All right. So I’m saying to you: “I’ve seen that better and we can do – we can get a little bit more out of that.” So I’m not so sure that we have these [points to mass values offered by students as part of equal-mass solution] right. So my question to you now is, How might you change it and why?  

Though Nancy’s utterance ends with a Req. I / P much like the one in the example from Sandy’s classroom, the kind of idea / proposal being requested is different which sets a different goal for this segment of the activity (which is labeled Proposing New Solutions): coming up with new ideas as opposed to figuring out why the previous idea didn’t work. As a result of this difference in the content of the goal-setting utterance, the dead end never is treated (formally at least) as an event from which something can be learned (other than what not to do).

There is one other way in which this middle portion of both of Nancy’s SPMs is different
from Sue’s period 1 and 3 lessons (and even the period 7 lesson). The exploration of the new set of proposals is much ‘messier’ – as indicated by the greater complexity of the diagrams at this point and the various lines connecting different segment objects – and the discussion of those proposals is much more in-depth – as indicated by the presence of the trapezoids indicating dialogue either supportive or critical of those ideas spanning at least several exchanges. It will be important to keep this latter feature of Nancy’s SPMs in mind as the analysis zooms in on the utterance-level action in the Interactions sub-section.

Framing the Activity

In a vein similar to Sarah’s approach to framing the activity, Nancy’s orienting effort was very minimalistic. A large portion of Nancy’s Building Up the Problem section was dedicated to reviewing an experiment which students had conducted the day before. She used this review as a segue into her discussion of the reaction of interest in the current activity; that discussion focused on building up the equation – particularly, on determining the formula of the product, which became an important tool for the students in generating their solutions. Once this background was provided to the students, Nancy officially posed the problem; below is her turn from the period 3 class in which that action was accomplished:

80. Nancy: All right, so here’s my question to you and this is what I want you to think about for a minute. Okay, actually take some time, think about it, write it down if you want to – [but] don’t say anything. You’ve got ‘6.54 grams’ of zinc. So, we’re going to the lab – you’re going to actually do this, right. And if I go to the lab and actually do this, I’ve got to weigh . . . I’ve got to mass some stuff out. That’s the only way I can do this. So, I’ve got ‘6.54 grams’ of zinc and I need to know how many grams of sulfur I should use to do this reaction. I need you to think about how much sulfur I should use and why I should use that amount. That’s your question. [1 sec. pause] Think about it for a minute.

Overall, Nancy’s framing provides no information about why this reaction is important, how students will determine if their solutions are tenable or not, and how they will go about
tackling the problem. [The only difference in the period 6 (regular chemistry) class was that Nancy did say – as she transitioned from talking about the previous day’s experiment to the discussion of the Zn-S reaction – that, “I want to do a reaction that actually happens in model rockets, okay” (line 48).] That these missing elements of Nancy’s framing segment did not sufficiently orient students to the goal of the activity or how to realize that goal was made clear in the following exchange which occurred in period 3 just before the test of the first proposal:

149. Nancy: All right. Should we try it? Are you ready? [Inserts Mg ribbon into the pile made from the Zn-S mixture.]

150. FS 1: Wait, whoa! I don’t get what we’re going to see.

151. Nancy: You don’t get what we’re going to see?

152. FS 1: Yeah. Like, what are we trying to do here?

153. Nancy: We are trying to make this . . . It’s going to react – it’s going to be a very exothermic reaction.

An excerpt from the interview with Cole from Nancy’s period 3 class makes apparent how this very minimal orienting discussion impacted his ability to evaluate the test results:

Well, I have never seen it before, so I had to like go off of the fact that, you know, we didn’t know what it should have done for it to be . . . We didn’t know if we were close or . . . you know, I didn’t know if we were close or really far off for how big the reaction was to be. So, it was kind of hard for me to determine where to go to next because . . . (section B.1)

One thing on which Nancy did focus in framing the activity was to orient the students to the periodic table as a key cognitive tool, which she did right after posing the problem in both classes (as well as re-orienting the students to it later when they were trying to develop new proposals). Karen (from Nancy’s period 3 class) indicated the influence of this when she responded to the researcher’s question about how she generated her new proposal: “I went straight to the periodic table, and the mass numbers I knew, sort of, probably, had to have meant something” (section C.2).
The Nature of the Interactions

The first point to be made in this sub-section will help account for the similarities in the structure of activity in the opening stages of the lessons in Nancy’s, Sandy’s, and Sarah’s classes which was noted in the SPM discussion. The following excerpts from the Proposing the First Solution segments of Nancy’s two classes will provide the data needed to make this point:

From period 3:

89. Nancy: So what do you think?
90. Several students: ‘6.54’
91. Nancy: ‘6.54’
92. FS 3: We’re geniuses – I’m telling you.
93. Nancy: Why do you think so?
94. FS 1: Equal parts.
95. FS 7: It has to be equal.
96. Nancy: Okay, so why does it have to be equal? What are we all about the equal for? Can’t we just use ’75 grams’ and get it over with? Why not?
97. FS 1: Because it wouldn’t have the same reaction.
98. Nancy: Wouldn’t have the same reaction.
99. FS 1: One would become more . . . dominant.
100. Nancy: Okay, so you . . . you want them to have equal parts because – give me a reason for that.
101. FS 1 followed by MS 4: The charges.
102. Nancy: Because they’re over here [pointing to the charges in the formula of the product ZnS] in equal parts, is that what you’re saying?
103. Some student: Yeah.
104. [Nancy shakes her head in acceptance]

From period 6:

71. Nancy: [MS 9], what did you say? How much do you think?

Nuc. I Req. I / P
72. MS 9: ‘6.54 grams’.

73. Nancy: ‘6.54 grams’. [5 seconds pause while she gets new marker to write on board and writes this value down under ‘S’] So he wants me to try ‘6.54 grams’. And why do you say that, [MS 9]?

74. MS 9: Because they both have two: one’s plus two, one’s minus two and I just reduced the numbers.

75. Nancy: Okay. So if they go together in a one-to-one ratio, the masses go together in a one-to-one ratio. Okay.

Before that first point can be made, the reader needs to be aware that each of the two excerpts brought the Proposing the First Solution segment to a close; following each of the sequences presented, the class went immediately into the Testing [the 1st] Proposal phase. The significance of this is that the reader should recognize that there is no request for evaluation or request for alternatives made in either sequence. Given the extent to which Nancy pushes the students in justifying their proposals in each sequence (a detail to be returned to below), the lack of a request for alternatives is probably the more significant omission: It is largely responsible for the linear flow of the exploration of ideas in the opening stages of Nancy’s lessons and is the reason her SPMs are similar to both Sandy’s and Sarah’s at the outset.

There are a couple of other points which can be drawn out of these two excerpts. The first is Nancy’s heavy emphasis on justification, which is particularly apparent in the period 3 extract. Finding the justifications given in lines 94 / 95 and line 97 insufficient, in each case Nancy makes additional requests for justification. As was noted in her sketch, this concern for “getting to the ‘Why?’” is a driving force in Nancy’s pedagogy and, throughout both of her lessons, she makes this norm very explicit. This is one of the distinguishing features between the interactions in Nancy’s lessons and those in Sarah’s, as Sarah had a greater focus on students’ problem-solving proficiency, and so her interactions revolved more around requests for elaboration – particularly in the dependent exchanges following solution proposals.
Related to this norm of justification in Nancy’s lessons, it is interesting that there is only a single request for justification in the sequence from her period 6 [regular chemistry] lesson. One must assume that the absence of additional requests for justification – such as were present in the period 4 excerpt – is indicative of the fact that MS 9’s initial justification was sufficient. Given Nancy’s concerns about conducting the MSP lesson in this regular chemistry class, it seems important to note such differences in the interactions between the two classes as the discussion in this section proceeds.

The final point to be developed from this first pair of extracts is related to the utilization of a re-utterance (RU) move by Nancy towards the end of each sequence. A key feature of these two RU moves is the way they made more obvious (in the case of line 102 in period 3) or filled in details of (in the case of line 75 of period 6) the reasoning associated with students’ justifications. In this way, perhaps more than any of the teachers in this study, Nancy used the re-utterance to support the mutual understanding commitment. A very sophisticated example of this application of the RU move can be found in the excerpt from period 3 below which occurs when FS 1 is trying to develop a justification for the new proposal she has made:

229. Nancy: Okay, so you want ‘6.54’ . . .

230. FS 1: Yeah, but less sulfur.

231. Nancy: . . . but then I would have to use less sulfur because . . .?

232. FS 1: . . . because . . .

233. Nancy: Metals are more reactive and having more metal than non-metal . . .

234. FS 1: Yeah, they’re just canceling each other out so they’re not making a reaction.

In line 231 Nancy makes a request for justification; in line 232, FS 1 starts to produce the
justification but, by her pause, shows that she is struggling to do so. Recognizing this cue, Nancy conducts her re-utterance move in line 233. What is significant about this is that Nancy is not re-uttering the immediately previous statement but she is fusing together a pair of statements that FS 1 had made prior to this excerpt (in lines 221 and 223) and generating the re-utterance from them. In so doing, Nancy is supporting FS 1 in the complex process of building an explanation with which to validate FS 1’s proposal. That this support accomplished its objective is clear in line 234 where FS 1 picks up where Nancy left off and completes the explanation.

A final example of the sophisticated way in which Nancy used the RU move to sustain the mutual understanding commitment is represented by this excerpt from her period 6 lesson:

   why do you think that [the 2nd mixture tested] worked better?

283. Unknown male student: Because there was less.

284. MS 7: <Because (inaudible).

285. Nancy: <Because there was less.

286. MS 8: I crushed it (inaudible).

287. Nancy [after a couple of seconds of wait time and of facial expressions indicating uncertainty]: Curiosity beyond curiosity. We had less sulfur . . .

288. FS 13: Right.

289. Nancy: So you . . . you know . . . Right – most people when they want to get a bigger reaction, they just think they just pour more stuff on it, right?

290. FS 13: Oh yeah!

291. Nancy [continuing her thought from 289]: ‘We should just pour more stuff in it.’ Why . . . why . . . We used less sulfur that time and we got a much better reaction – once the magnesium got there, we got a much better reaction. <So this is my question to you: Why?

Part of the goal of Nancy’s turn in 285 is to gently indicate that MS 6’s response in 283 is not sufficient (as her turn in 291 indicates). However, there was another thing which this
utterance accomplished: It laid the groundwork for the set of turns (287, 289, 291) in which Nancy juxtaposes MS 6’s idea (through a second RU in line 287) with a misconception commonly held by introductory chemistry students – the ‘more is better’ fallacy. With her re-utterance in line 287 (“We had less sulfur”) and her statements in lines 289 and 291 (“most people when they want to get a bigger reaction, they just think they just pour more stuff on it” and “We should just pour more stuff in it”), Nancy has held MS 6’s idea up against this misconception. In doing so, she has prompted the other students to think about the significance of MS 6’s statements as it relates to (and opposes) this commonly-held fallacy.

The next aspect of the interactions in Nancy’s classes to discuss connects to a point which was alluded to within her sketch. This aspect is best understood through the examination of a set of sequences found at the beginning of the Proposing New Solutions segment:

**Sequence 17**

137. Unknown male student: I’m thinking less [sulfur].
   Att. I *Give I/P*

138. A couple of other male students [towards front of room]: Less.
   Att. I *Give I/P*

139. Nancy: Okay, so now [1 second dramatic pause] . . . let’s try and make it better.
   [Monologic – this is supported by the lack of uptake of responses that follow]

140. MS 12: Let’s do it.
   Att. R

141. MS 8: Let’s go with five.
   Att. R *Give I/P*

142. Nancy: Let’s say . . . <not so good, right.  
   Att. I
   <<I’m seeing spots . . . anybody else seeing spots?
   Emb. I

143. MS 6: <We have to make it unstable.  
   <<We’ve got to make it unstable.
   Att. R *Give I/P*

144. Several students [in response to Nancy’s question in 142]: Yes!
   Emb. R

**Sequence 18**

145. Nancy: So, let’s try . . . let’s try something else. I wanna make that better. So ‘6.54’ and ‘6.54’ not doing so great, okay. So now I need you to think for a couple of minutes and think about
what might make it better, and I want you to write it down before
you say it, because I know everybody’s anxious to share but I
want everybody to have a chance to think, okay. So what do
you think might make it better? I asked you to bring your book
and I asked you to look at a periodic table . . . they might be
two hints for ya. Look around. What might make it better?
Write it down.

146. MS 12 (~5 sec. after Nancy’s turn): More of one,
    less of the other.

147. Unknown male student: Huh [related to MS 12’s suggestion].

148. MS 7 [likely to unknown male student]: Do you agree with
    that?

149. Nancy: Now remember, it’s a given <that I’m startin’ with
    Mull it over. Come up with a reason.

150. Unknown male student up front: <You need more sulfur.

[*Lines 147, 148, and 150 cannot be given function codes because (1) line 147 seems to be the
unknown male student making fun of MS 12 for how obvious his solution is, but that is not
certain and (2) it is not clear whether MS 7’s question in 148 is directly related to MS 12’s
solution or something else that has been said. Line 150 is clearly a response to MS 7’s
question in 148, but it is not clear if it is related to 146.]

[There are 11 more turns in this sequence, but they are not relevant to the point being made.]

Sequence 19

162. MS 8: Lower or higher?
163. FS 13: I think higher [amount of sulfur].
164. Unknown female student: I think lower [amount of sulfur].
165. MS 8 [referring to FS 13’s idea]: Me too.

[*These are all coded as Prep. because they occur before the ideas are shared out with the whole
class – which occurs starting with line 168 – and also because they receive uptake from Nancy
in this line.]

166. Nancy [18:35]: Okay, so we’ve got . . .
167. [A few students continue to argue this point.]
168. Nancy: ... we’ve got some people saying, ‘I think higher’, we’ve got some people saying, ‘I think lower’. So let’s just go ... let’s try someone who said ‘higher’ first. [Makes facial expression] All right, so ... how much higher?  

Nuc.  I  Req. I / P

Nuc.  R  Give I / P

169. MS 8 [18:48]: ‘13.08’.

The feature of interest is represented within the codes found in sequences 17 and 18. As part of the coding system used, any main code (e.g. Give I / P, Ref. Reas.) representing a key discourse action not receiving uptake in a whole-class discussion was typed in italics. There are five such instances in those first two sequences. This is representative of Nancy’s concern for getting students “to that independent thought” (a quote from her sketch) by giving everyone in the class a chance to think before anyone speaks – a concern she makes explicit in line 145. As a result, there are numerous instances (11 in her two classes) where she does not engage in uptake of students’ ideas until after there has been a period of individual / small-group contemplation. The one problem with this practice is that sometimes it results in valid / interesting ideas never getting explored because they do not get repeated during the times in which Nancy is willing to accept them. For instance, from the above excerpt, neither MS 8’s suggestion to use five grams of sulfur (line 141) nor MS 6’s intriguing statement concerning the need to make it [the mixture?] unstable (line 143) ever get re-introduced into the whole-class conversation in sequence 19.

Through the discussion of this next aspect, a unique opportunity will arise because it will represent one of the few cases where an element of the discourse can be compared directly across most of the lessons. This is possible as a result of the fact that the same idea surfaced in at least one lesson for four of the five teachers (everyone but Sandy). That idea is the misconception – often held by introductory chemistry students – that metals are more reactive than non-metals.

In three of the lessons in which it appeared (in Sarah’s, Hannah’s, and Marty’s classes), the idea was largely accepted without further discussion and without critical analysis by either the teacher
or by other students, even though it was constantly being used as the justification of a proposal. What happened in the occurrence of this idea in Nancy’s classroom was quite different. The assertion is first made by FS 1 in the Analyzing the [1st] Test segment as part of her offering of a new proposal (line 171). As was discussed above, since Nancy had not formally made a request for new proposals nor given the class time to generate such proposals, there was initially no uptake of this idea. Later, when those two criteria are met – in the beginning of the Proposing New Solutions segment – then there can be uptake of this idea, and that is where the excerpt of interest is taken from (codes have been removed from this excerpt to save space):

219. FS 1:  We need more zinc because zinc’s a metal – right? [To Nancy]
220. Nancy:  Okay.
221. FS 1:  And metals are more reactive and so for this reaction, you’d have to elevate it [the amount of zinc].
222. FS 5:  Wait.
223. FS 2:  Did she say ‘less sulfur’?
224. FS 1:  Yeah, less sulfur, more zinc.
225. Nancy:  Less sulfur, more zinc. So, okay . . . so . . .
226. FS 1:  I mean, keep that amount of zinc [since Nancy had given them that to start with] . . .
227. Nancy:  Okay, so you want ‘6.54’ . . .
228. FS 1:  Yeah, but less sulfur.
229. Nancy:  . . . but then I would have to use less sulfur because . . .?
230. FS 1:  . . . because . . .
231. Nancy:  Metals are more reactive and having more metal than non-metal . . .
232. FS 1:  Yeah, they’re just canceling each other out so they’re not making a reaction.
234. FS 1:  You know what I mean? Because that’s [sulfur] less reactive, so if you have a less reactive with a reactive then zinc is actually being used up.
235. Nancy:  I guess my question to you is, why do you think that zinc is more reactive?
236. FS 1:  Because it’s a metal.
237. Nancy:  Yeah. So?
238. FS 1: Yeah, but metals are more reactive than non-metals.
239. Nancy: I mean, a lot of things are [metals]. I mean, most of the [periodic] table, right?
240. FS 1: Yeah, but zinc seriously is reactive, isn’t it?
241. Nancy: Well, let’s think about our trends, if you want to. Think about our trends in the periodic table, okay. Our trends in the periodic table say that electronegativity does what across?

[The exploration of FS 1’s assertion that metals are more reactive continues until line 256 when this concluding exchange occurs . . .]

256. FS 1: So, you’re saying I’m wrong!
257. Nancy: Okay, I’m not saying you’re wrong, I’m giving you a reason, right? Okay, so, I’m not necessarily saying that your idea is wrong, I’m saying your reasoning [pause] doesn’t hold. Okay?

As compared to the other three instances of this misconception surfacing where there was usually only a single exchange around it and never any evaluation of it, in this instance there are 40 turns of dialogue devoted to it. Through this extensive dialogue, this misconception is thoroughly examined and the dissatisfaction criterion for promoting conceptual change (Posner et al. 1982) is met. While one could criticize Nancy for not involving more students in this discussion (she does so in the omitted portion), her commitment to giving this idea the fullest consideration possible is noteworthy because one of the potential values of the MSP structure is in bringing such notions to the fore so that they can be appropriately explored. This excerpt is representative of the way Nancy utilized this potential of the MSP structure within both of her enactments of it.

One additional point needs to be made before leaving this extract. In her last turn, Nancy makes an important distinction in responding to FS 1’s statement – between an idea and the reasoning behind it. This is significant in terms of creating a norm for the interactions related to the openness commitment which indicates that the two must be considered separately. Just as significantly, Nancy is sending the message that this discourse is not about right or wrong – it is about the thinking the community of inquirers does surrounding the ideas which are presented.
Related to the point just made, this sub-section of Nancy’s case study will be concluded with an example where the idea / reasoning distinction is a critical feature of the interactions – an example chosen because of its implications for the mutual understanding commitment. It took place in the Proposing New Solutions segment just following the set of sequences presented previously (in which several student ideas were not taken up in the whole-class discussion):

166. Nancy: Okay, so we’ve got . . .

167. [A few students continue to argue about different proposals.]

168. Nancy: . . . we’ve got some people saying, ‘I think higher’, we’ve got some people saying, ‘I think lower’. So let’s just go . . . let’s try someone who said ‘higher’ first. [Makes facial expression] All right, so . . . how much higher?

169. MS 8: ‘13.08’.


And <how did you come up with that number?

171. FS 13 [almost as a response to MS 8’s value]: <I was thinkin’ like ‘10’ [grams of sulfur].

172. MS 8: <<I multiplied it by two.

173. Unknown male student: <<Yeah, you’re thinking, like, ‘10’.

[**This is an embedded exchange because it never gets taken up by the larger class. FS 13 is both offering a different I / P and refuting MS 8’s value and the unknown male student is agreeing with her.]

174. Nancy: Okay, so you multiplied it by two. For any reason?

175. MS 8: Because the weight of zinc is heavier than sulfur.

176. Nancy: So the weight of zinc is heavier [1 second pause] . . . <than the weight of . . . the weight of zinc is heavier than the weight of sulfur, <<so you think you need more of this [sulfur].

177. Unknown male student: <Isn’t it twice as much?

178. MS 7 [to unknown male student]: <<Approximately.

179. MS 8: About two times.

Okay. [2 sec. pause] So you’re gonna end up. [2 sec. pause as she looks at what she has written; throws both hands up]
Okay [looks over towards camera]. All right. So the weight of zinc is heavier so we’re gonna double it. All right, so let’s [hand gesture towards MS 8] . . . I understand that – I understand that concept. Okay.

181. Unknown male student: That’s a lot of sulfur.

182. Nancy: It is a lot of sulfur.

The first interaction within this excerpt to note is the one that occurs in line 171 when FS 13 indicates her disagreement with MS 8’s proposal of ‘13.08 grams’ as an appropriate amount of sulfur on the higher end of the scale. What is significant about this utterance is that there is no uptake of it so neither her alternative value nor her reason for disagreeing with MS 8 are pursued.

The second interaction of note is in lines 170, 172, and 174 – 176 when MS 8 offers his validation for the ‘13.08-gram’ proposal. What is important about this is not the nature of the interaction, but the content of MS 8’s utterances: He presents the most sophisticated justification for a proposal in the entire set of Zn-S reaction lessons (despite the fact that he is in Nancy’s regular chemistry class and was not one of the two gifted students in this class) – a justification requiring him to recognize the need to make the gram-mass ratio of the elements proportional to the atom-mass ratio. [Unfortunately, in carrying out the conversion needed to produce that proportionality, he has gotten his conversion factor backwards.]

Immediately following this second interaction, there is an embedded exchange (lines 177 and 178) between two male students which is significant because it indicates that they are following at least a part of MS 8’s reasoning. A careful examination of Nancy’s turn in line 180 which follows this exchange suggests that she is having some difficulty completely grasping this reasoning (perhaps because of the error MS 8 made). As Nancy acknowledged in a post-lesson interview (4, section D.4), she did not fully understand what MS 8 had done to generate his
value. This suggests an aspect of the mutual understanding commitment not considered previously: that the teacher – who is normally the facilitator of the discussion in these whole-class segments of an MSP lesson – must make sure that they completely comprehend students’ ideas so that they can better guide the conversation around them.

The impact of Nancy not totally grasping MS 8’s line of thinking becomes apparent in the last interaction in this sequence. In it a male student questions MS 8’s idea (but not his reasoning) on purely empirical grounds, and then Nancy echoes this thought. From that point forward – through the testing of another proposal and the analysis of that test, up until the time this proposal is itself tested – MS 8’s idea carries the tag of this empirical criticism with it. This is important because the focus on the idea itself and not on the reasoning behind it means that this proposal is not treated as a viable resource for developing other lines of thinking – a fact that becomes quite significant in the Formalizing the Solution segment of the period 6 lesson.

**Formalizing the Solution**

To set the stage for this discussion, a portion of Nancy’s opening turn in the FtS segment of her period 3 class is presented:

356. Nancy: All right. So here’s the thing: The other day when we started doing this, I said you needed your book and your periodic table – and you still need them. Okay, so would you get those out. I need you to think about ‘why’ now. We finally got it to work. We got the answer. We know approximately why – I mean, we were talking about atomic masses – we know were in there somewhere, right. But I need to know why this one [‘3.21 grams’] worked and the ‘6.54’ didn’t.

There are two aspects of Nancy’s approach to Formalizing the Solution which are apparent in this excerpt. The first is that Nancy clearly expressed an objective of connecting the scientific explanation to both the successful and unsuccessful solutions, which makes her approach to conducting this segment similar to Sandy’s and Sarah’s approaches. The second
feature represents a marked difference from Sandy’s approach and a difference in degree from Sarah’s approach: Nancy put almost the entire onus of developing the scientific explanation on the students, allowing them to use their books and periodic tables, to talk to each other, to struggle, and to grope around in an effort to derive such an explanation. That second feature of this effort is captured in the following excerpt from the FtS in Nancy’s period 3 class:

360. Nancy [52:26]: (Inaudible) so let’s start now. Does anyone have anything they want to share? [MS 4]
361. MS 4: Uh, I said that it had to . . . they had to be like that because the ratio of particles had to be equal.
363. MS 4: So the particles . . .
364. Nancy [interrupting]: Let me write that down. [On the board she writes, ‘The ratio of particles had to be equal’.] [Part way through this she says . . .] I’m not sure what you mean by that, that’s why I’m writing it down. [Finishes writing] Expand on that for me. What do you mean by ‘particles’?
365. MS 4: I don’t know, it just sounded good. [It appears that this is something he got out of the book by the way he is looking at it.]
366. Nancy: Parts or wholes – which . . .? [Apparently asking whether he wasn’t sure of the whole explanation or just part of it]
367. MS 4: Like the part . . .
368. Nancy: The ratios . . . I’m thinking you’re on the right track here, because we got the ratios in there. [Short pause] And then, does anybody else have something? I mean, I’m just going to write ideas up here. Maybe we can put them together into something that makes sense. [MS 9], what do you got?
369. MS 9: Basically this whole ‘Av-o-gadro’s’ constant thing [looking down at the book as he reads it out] . . .
371. MS 9: Basically, it combines ratios and, um, masses of atoms.
372. Nancy [after writing that information on the board]: Okay.

Eventually, when students had built up some of the key ideas and had most of the pieces in place for developing the scientific explanation, Nancy would take over the process and synthesize these different bits of information. Conducting the Formalizing the Solution in this
way involved a significant investment of time, as this segment lasted over fifteen minutes in both
of Nancy’s classes, far longer than the amount of time devoted to it in Sandy’s classes (an
average of around 10 minutes) and in Sarah’s classes (an average of around 6 minutes).

To bring this sub-section to a close, a point about the FtS specific to Nancy’s period 6
class needs to be made. It was noted at the end of the Interactions discussion that MS 8 had
made a proposal which, while flawed in terms of the value (idea), was quite sophisticated in
terms of the justification (reasoning). However, because of an empirical criticism of the value
(idea) itself, the reasoning was never used as a resource for understanding the explanation behind
the solution to the Zn-S problem; Nancy did not reference MS 8’s idea once in the FtS segment.
Instead, Nancy tried to build the explanation off of the successful proposal made by FS 14.
Unfortunately, FS 14 herself only understood the logic of this proposal at a macro level (as an
interview with her confirmed) – not at the micro level as MS 8 had understood his proposal. It is
perhaps because of this set of circumstances that the there was even more struggling and groping
by students in working through the FtS segment in this class than there was in period 3.

Hannah’s Lessons

A Sketch of Hannah

Hannah had a long history of affiliation with the researcher and with the ICISS group
prior to her involvement in this study. One of her science teaching methods courses – in which
the researcher participated on a regular basis – was taught by the researcher’s academic advisor
and leader of the ICISS group. Within that same semester, Hannah was supervised by the
researcher during a field experience as part of her pre-service teacher preparation program.
During the year in which this study was begun, she had taken over the researcher’s teaching
position following his resignation (and been recommended by the researcher for that opening).
Hannah’s responsibilities in that position involve teaching or co-teaching three different chemistry courses: Chemistry I (in which the data was collected), Organic Chemistry and Chemistry II (the course she co-teaches with Sandy).

Probably more than any other participant, Hannah embraced the notion of the MSP lesson structure and of the commitments of progressive discourse that undergird it. This is likely because it aligned so well with key aspects of her teaching philosophy. One of those aspects surfaced in interview 1 during Hannah’s discussion of her view of what scientists do:

Like, I see scientists doing research – I did a research internship – as constantly being able to analyze what they’re finding and change their mind. And I feel like students resist that change-your-mind step. They just want to get there – to whatever the answer is. So, I think that’s what I’m trying to undo. (Section D.1)

This aspect was even more poignantly expressed later in the same interview in her response to a question about whether engaging students in MSP-like lessons might translate into a shift in their concern with just getting the right answer in the laboratory: “Yeah . . . yeah, it’s kind of the same idea. Like, you know that [pause] the quest is just as important as the answer” (section F.6; emphasis added). Both of these excerpts speak to a focus on reasoning – and to a concern for the openness commitment – which creates a parallel to the way Nancy stressed justification.

Additional excerpts from her interviews indicate the implicit recognition of the importance of at least two of the other three commitments of progressive discourse. The first of these excerpts represents Hannah’s reply to what she considered ‘meaningful dialogue’ in the science classroom to be, but it also captures the spirit of the expansion commitment:

So, I think, um, them expressing – first of all – to each other what they think and then . . . but then building off of each other and sort of . . . I imagine it sort of as like them working through a problem together and so one student may be presenting something and then they take part of it and make it better. (Interview 1, section B.2)

The second of these excerpts – which occurred later in the discussion of the same topic –
indicates Hannah’s concern with promoting greater levels of student-student dialogue in her classroom, but it serves equally well as a symbol of the inherent value she places on the empirical testability commitment:

Like, I try to get them all of the time to analyze data: ‘Don’t tell me what you think should happen, tell me what this [their data] says did happen.’ And so, if they’re talking to me, like, they know that you have some expectation of what should have happened and they’re always like trying to get you to tell them or to give it away. Whereas with each other, I think they do that less. Even if one of the other students is saying, ‘This is the answer,’ they still might not trust the other student. (Interview 1, B.4)

With so many of Hannah’s espoused beliefs allied to the principles of progressive discourse, it will be an intriguing storyline during the analysis of the discourse data from her lessons to consider the extent to which her classroom practices – as manifested in the interactions observed – are representative of those espoused beliefs.

*Solution Pathway Maps*

One of the most important things that Hannah’s SPMs indicate is that, in terms of the structure of activity, her enactments of the Zn-S reaction lesson were more like Marty’s Periodic Table investigation than they were the other three teachers’ versions of this lesson. For instance, it was noted previously that Hannah’s students spent a somewhat higher percentage of the total activity time in small-group work than the students in Sandy’s, Sarah’s, and Nancy’s classes; this was true of Marty’s students as well. Also, during these small-group activity segments, both Hannah and Marty regularly interacted with the students whereas Sandy, Sarah, and Nancy rarely did so. Finally, and most importantly, there was a different relationship between the product of that small-group work and the action within the whole-group segments: Whereas only a couple of ideas generated in the small-group work would become explored in the whole-group segments of Sandy’s, Sarah’s, and Nancy’s lessons, there was an expectation that all groups
would share out their ideas in Hannah’s and Marty’s lessons and that all of these ideas would (at
least potentially) make it into the testing phase. In this sense at least, Hannah’s and Marty’s
lessons truly involved the exploration of multiple solution pathways.

A caveat injected into the next-to-last statement in the paragraph above needs to be elaborated upon. While Hannah made clear to her students that the possibility existed for each of their samples to be tested for its efficacy, in her periods 1 and 4 classes (taught on the first day of videotaping), this is not what happened. The cumbersome structure of activity – which involved picking a group whose sample would be tested, having the group prepare that sample, conducting the test, and then providing time for the remaining groups to revise their plans based on the test results – while conducive to allowing some significant interactions (to be discussed in the *Interactions* sub-section) to take place, consumed too much time to make feasible the testing of all proposals. As a result of this, in her period 3 class (taught on the second day of videotaping), she streamlined the structure of activity so that all groups prepared the samples in the same activity segment, and all groups had their samples tested in the subsequent segment. The trade-off for this more efficient activity structure was that some of those significant interactions mentioned above (and to be discussed later) were no longer possible.

A final point to be made about Hannah’s SPMs is that they depict an activity segment not found in any of the other teachers’ lessons: Revising the Plan. The goal of this segment was to use the results of the testing which had occurred in the preceding segment to inform any appropriate changes in the proposals that the groups had initially generated. Given this goal, it should be obvious that this is one of the activity segments which involved small-group work; this will be an important piece of information to keep in mind when the interactions that took place within it are addressed in the *Interactions* sub-section.
Framing the Activity

Of the four teachers who conducted the Zn-S reaction lesson, Hannah appeared to give the most attention to orienting her students to the activity. Hannah set the stage for the lesson by presenting the students with a Question of the Day which revolved around writing the balanced equation for the Zn-S reaction and identifying the type of reaction it represented. (Significantly, Hannah neither went over this question in the whole-class discussion comprising the Building Up the Problem segment nor wrote this information anywhere visible, a point to return to later.)

The framing segment was begun by talking about why the Zn-S reaction was of interest – i.e. pointing to its use in model rocket engines. Once the significance of the reaction was established, Hannah played a video which she had made herself and which showed her igniting a perfect mixture of the two reactants. This video served several purposes: (1) Further orienting students to the goal of the activity; (2) creating a strong motivational basis for students to participate in the activity; and (3) providing a point of reference for evaluating the results of the empirical testing students would do. Related to that third purpose, in her period 4 class, Hannah replayed the video at 20:06 of the lesson to show students the difference between her sample and one just tested which burned fairly well but took a while to ignite.

After the video was done playing, Hannah supplied students with a hand-out designed to guide them through the activity. This hand-out began by creating the context for the problem as well as presenting some of the parameters related to solving the problem (this will be revisited below). The bulk of it, then, was dedicated to delineating the actions the students needed to perform during the activity, such as ‘Justify Your Plan’, ‘Revise Your Plan, and ‘Compare [Results of Testing]’ (many of these actions correspond to key principles of her teaching philosophy, as she pointed out in interview 3). As compared to the one used by Sarah, this hand-
out had a much greater emphasis on the process of the problem-solving activity rather than the content of it. This focus on process in Hannah’s hand-out likely contributed to her being able to engage students in a structure of activity which was much more complex than that found in the enactments of the other three teachers conducting this lesson.

There was one feature of the content of this hand-out which became an unintended hindrance to the exploration of ideas by students. One of the parameters Hannah set for the problem was, “Hint #2: You do not need more than 15 grams of sulfur” (from the hand-out; emphasis added). When the initial proposals in the three classes engaging in this activity were carefully examined, it was found that five of those 18 proposals were based on this maximum limit. Even more interesting, the one group in period 1 who eventually generated the ‘correct’ solution had initially come up with a value based on this maximum amount of sulfur (as was revealed in an interview with Mark from that group). In interview 4 (A.2), Hannah indicated that she had only set this limit because of the number of different tests she expected to run and that she had not anticipated the influence it would have on students’ orientation to the problem space.

The final point to be made about the way Hannah framed this activity is that she did not make very salient – in either her discourse or the hand-out – either of the two cognitive tools essential to solving this problem: the chemical equation and the periodic table. As noted above, even though the chemical equation was the topic of the Question of the Day, it was not made highly visible to students in the way that it was in Sandy’s, Sarah’s, and Nancy’s classrooms. Perhaps because of this, only one group specifically referred to the equation in their give justification move during the Sharing Out segment of the activity. There was an equally interesting situation with regard to the use of the periodic table by students as a resource for solving the problem: In each class videotaped, only one group produced the scientifically-
accepted solution to the problem, and in each case that group was positioned directly beside one of the two periodic tables hanging in Hannah’s room. Further, in each case a member of the group can be seen pointing to the periodic table during the Generating Solutions task segment.

The Nature of the Interactions

In preparation for discussing the first feature of the interactions in Hannah’s lessons, it is important to point out that in the hand-out she gave to the students (overviewed in the Framing sub-section), there were two explicit “hints” provided. This fact needs to be kept in the back of the reader’s mind as the following excerpt is examined. It comes from one of the sequences in the Sharing Out Solutions segment of Hannah’s period 4 class (codes have been removed):

65. Hannah: Okay, so you did similar to them [previous group to present], but you chose less why?
66. MS 3: Because the zinc is more reactive, so we just chose five for sulfur because it was less.
67. Hannah: And [points to back right corner group to indicate it is their turn to present] . . . Oh wait, what’d you say [to FS 14]?
68. FS 14: (Inaudible, but something about how the elements react)
69. Hannah: No . . . not me – I forgot everything.

Before addressing the main interactional feature of this excerpt, it should be noted that, within the opening exchange, the ‘metals are more reactive’ misconception appears in MS 3’s justification (line 66). Much as was described in the discussion of how this misconception was handled by different teachers within Nancy’s Interaction sub-section, Hannah largely allowed it to go un-addressed and unchallenged in the excerpt above. Through an examination of the remainder of this excerpt, it may be possible to understand why she handled MS 3’s utterance in this way. Following the initial exchange just addressed, Hannah is about to move onto the next group, when FS 14 says something which Hannah asks her to repeat. Although FS 14’s utterance is largely inaudible, it is clear from Hannah’s follow-up (line 69) that FS 14 either
sought information related to MS 3’s idea or made a statement on this topic for which she wanted an evaluation from Hannah. In Hannah’s follow-up, she indicates that she will not be providing such information – i.e. there will be no further ‘hints’ beyond what was in the hand-out – forthcoming. This is a strategy (of not offering such hints) which Hannah maintained through all of her MSP enactments. It may have been because of this strategy that Hannah did not pursue the ‘metals are more reactive’ misconception any further following line 66.

The significance of this practice becomes evident in a second excerpt, taken from the Idea Generation segment of her period 4 class:

35.j.(1) MS 1 [to his group members]: We can do a one-to-one [ratio], we can do a one-to-two, (inaudible).

j.(2) MS 1 [several seconds after above turn]: This is really, I think honestly, just a matter of destiny. We can make up any logic we want.

j.(3) Hannah: You think it’s just random?

j.(4) MS 1: No, it’s not random, we just don’t have any way of figuring <out what it is.

j.(5) Hannah: <Figuring it out.

In this extract Hannah overhears MS 1 struggling – out loud – to develop a proposal based on the proper ratio of zinc to sulfur; the problem is determining what ratio is appropriate. Jumping into this discussion, Hannah is able to get MS 1 to indicate that there is a way to figure out the ratio – he just doesn’t know what that way is (representative of the fact – noted in the Framing sub-section – that the chemical equation was not salient to the students). Hannah could have provided a hint regarding a means for figuring out the ratio, but did not do so. There are several other places in the period 4 transcription where MS 1 and his group can be heard still struggling with this issue – and Hannah even refers to it in the Formalizing the Solution segment.
There is a significant question suggested by this feature of Hannah’s MSP enactments: To what extent should teachers allow students to struggle in this manner and refrain from supplying hints to them? There are, of course, motivational concerns at play here which must be taken into account when answering this question: How does the teacher balance the frustration which can arise in students under such circumstances against the desire to get students to think for themselves? There is another aspect of this question which is quite important for this research: In the majority of cases, these struggles which students experience in the small-group segments of the activity do not get shared out with the rest of the class in the whole-group segments – this was certainly the case with the ‘ratio’ struggle experienced by MS 1 and his group. The implication of this for the MSP structure must be considered in chapter 5.

The next interactional feature to examine is one which directly results from a difference between the participant framework (O’Connor & Michaels, 1993) employed by Hannah (and Marty) in the Idea Generation segments and that utilized by the other three teachers. As was noted in the SPM sub-section, whereas Sandy, Sarah, and Nancy remained removed from the groups of students as they were developing their ideas in this segment, Hannah (and Marty) continuously checked in with groups to find out about their progress and see what they were thinking. This had an important effect on the nature of the interactions in the subsequent Sharing Out Proposals segment, as this next excerpt (from Hannah’s period 1 class) shows:

23. Hannah: How many?  
   Why?  
26. MS 11 [reading off paper]: Because too much sulfur might suffocate the reaction.  
27. Hannah: Okay.
[MS 5], you justified that a little step further. What was it?

28. MS 5 [receiving paper from MS 11]: Um, not much sulfur’s used in gunpowder. It’s only a little bit.

29. Hannah: So you’re thinking this reaction’s probably similar to that?

30. MS 5: Yeah.

31. Hannah: Okay.

Through the first four-and-a-half turns (up to the second half of line 27), this follows the typical pattern which was found in the sequences in the Sharing Out Proposals segment of Hannah’s lessons. However, something different transpired in line 27 when Hannah asked MS 5 to elaborate on his group’s justification even though MS 11 had been presenting. So why did this happen? During the preceding Idea Generation segment (sequences 8 and 15), Hannah had talked to this group and gained insight into both the value they would be proposing and the rationale for it. As she indicated in a side conversation with the researcher, Hannah found the connection that MS 5 had made to the chemistry of gunpowder interesting. Because of this prior knowledge, Hannah was able to use her initiation move in line 29 to both insure that this connection was shared out with the larger group (supporting the mutual understanding commitment) and that MS 5 was framed as the author (Engle, 2006) for having made the connection.

Groves and Doig (2004) described a common pedagogical practice in Japanese mathematics classrooms identified as “kikan-shido – “between desk walking” or “purposeful scanning”” (p. 499). Clearly, the participant framework Hannah employed during the Idea Generation segment emulated this practice. In addition to the way she used this to influence the interactions in the subsequent Sharing Out segment as described above, Hannah also utilized this technique to manipulate the order in which students presented their proposal – always insuring that the group who had come up with the normative scientific solution went last. At the least, this meant that the normative explanation was the most salient to the students as they moved into
succeeding phases, such as Revising Their Plans.

There was another interactional strategy which Hannah employed to give prominence to
the normative explanation offered in each class. It is represented in the following excerpt from
the final sequence in the Sharing Out Solution segment of her period 3 class:

71. FS 18: Um, well we knew that ‘65.4’ was the atomic mass of zinc, and ‘32.1’ was the atomic mass for sulfur, so we just moved the decimal to the left because it [the hand-out] said the zinc to start was like ‘6.54’ – so that moved the decimal. So we got the atomic mass of the other one [sulfur] and moved the decimal to the left.

72. Hannah: Okay.

I just want us to hear that one more time because a couple of people looked like maybe they’re not following. Let’s try [FS 19]; [FS 19], can you do the same exact explanation?

73. FS 19: Um . . . zinc’s atomic number – or, atomic mass is ‘65.4’ . . .

74. Hannah: On the periodic table, you mean?

75. FS 19: Yeah.

76. Hannah: Okay.

77. FS 19: And then sulfur’s was ‘32.’ [pause while she checks paper] . . . ‘.1’. And then just . . . and you said the most we could use was ‘65.4’ [meant ‘6.54’] – which is moving the decimal over to the right.

78. Hannah: Okay.

The request for re-explanation move (used by Hannah in line 72) was first encountered in
Sarah’s Interaction sub-section. There it was pointed out that Sarah used it to see if someone in
the class other than the current presenter comprehended the logic of various steps in a calculation
being conducted. In Hannah’s application of the move, she used it to see if another member of
the same group presenting understood the justification being offered as well as the presenter. In
another application of this move in her period 4 class, she used it differently: She had the same
student who initially presented the explanation do so again to members of a different group so
that those members could evaluate that student’s idea against their own idea. These two different applications, though, had a common characteristic: They involved a re-explanation of the normative solution; Hannah never made a request for re-explanation of any solutions but the normative ones. Hannah utilized the request for re-explanation move related to this solution in each of her classes, except period 1, where, as will be seen below, this solution was re-entered into the conversation through a different vehicle.

The next feature of the interactions to discuss relates to a discourse move which was much more prevalent in Hannah’s lessons than any of the others, both because of the structure of activity and because of Hannah’s desire to keep students engaged during down time. A set of sequences representative of the interactions occurring around that move was presented in the Research Methods chapter (in the Coding Functions sub-section); one member of that set (from the Conducting a Test III segment of Hannah’s period 1 class) will be revisited here:

Sequence 59

128.d.(1) Hannah [28:10; to FS 6]: What are you thinking?  
   d.(2) FS 6: I don’t know. I think it’s going to be too much [sulfur].  
   d.(3) Hannah: And so, what will happen?  
   d.(4) FS 6: (Inaudible, but she does say something to the effect of “I think it’s going to die”)  

It is the request for prediction move found in this sequence which is of interest here; Hannah used this move more than any other teacher (15 instances in her lessons). However, given the structure of activity within her enactments (particularly, the fact that each group got to generate, propose, and potentially test their own solution), in itself this would be a trivial fact not worth reporting. There are, however, other aspects of the interactions associated with the request prediction move warranting further discussion of it.

One of those aspects was addressed when the larger set of sequences from which the
above excerpt came was discussed in the *Research Methods* chapter. Hannah often conducted this move using the ambiguous utterance, “What do you think (are you thinking) . . .?” as in sequence 59. Different students interpreted this utterance differently; in sequence 59, FS 6 initially interprets it as a request for evaluation. The dependent exchange which follows FS 6’s evaluative response indicates that Hannah still wants a prediction from FS 6. What is interesting is that, in the cases where students interpret her initial utterance as a request for prediction, there is never a request for evaluation in the subsequent dependent exchanges. This seems to indicate an emphasis on the empirical testability commitment (captured in the request for prediction) over the openness commitment (captured in the request for evaluation), although it would be expected that students have to perform an evaluation of the idea in order to make their prediction.

Two more points concerning the request for prediction (and request for evaluation) move need to be made. The first is that these moves were only found in the Testing Proposals and Revising Plans segments. The significance of this fact is that these two task segments always involved small-group discussions in Hannah’s classes. Considering that these moves represented the only form of a vetting process found within Hannah’s lessons, and that this vetting process was therefore never embedded in a whole-class conversation, this begs the question, ‘What impact is there on the openness commitment when the critical analysis of ideas occurs in this manner rather than in a larger group discussion?’

The final point to be made in this regard is that the change in the structure of activity in Hannah’s period 3 class (where everyone prepared and tested their samples in the same task segments) meant that the opportunities for Hannah to conduct the Req. Pred. / Req. Eval. moves were largely reduced in this class. There were no request for prediction and only three request for evaluation moves in this class, which translates into less attention being given to the
openness commitment as a result of this modification in the structure of activity.

Through all of the discussion of interactions which has occurred up to this point (including the sub-sections found in the other three teachers’ case studies), the teacher has always been one of the key participants in the action of the discourse event. This is a function of the fact that the teachers ‘held the reigns’ of the conversation the majority of the time and that student-student interactions – at least during the whole-class-structured segments of activity – were quite rare (as the data which will conclude this chapter will show). However, there was an important type of interaction which took place which often linked students’ utterances to each other – albeit somewhat indirectly – and there were several significant examples of this kind of interaction found in Hannah’s lesson. One of these transpired in her period 1 class at the beginning of the Testing Proposal II segment when Hannah asks a student to present his ‘revision plan’ (a plan based on observing the results of a test which may represent a modification of the group’s original proposal) to the class:

102. Hannah [after picking new name out of bag]: Okay. [MS 3], what’s your ‘revision plan’ or are you holding to your original? Nuc. I  Req. I / P
103. MS 3: Well, we took [MS 8]’s idea because we noticed that . . . he said that, um, the mass [of zinc she had given] was equal to the atomic mass [actually, he had said 1/10] . . . Nuc. R  Mod. I / P
104. Hannah: Uh-huh. Backchannel
105. MS 3: . . . and so that’s the same as one mole, so we’re going to try and use one mole of sulfur. [Cont. Nuc.—R from 103, Mod. I / P]

There are two important things in this excerpt. The first is that a group actually indicates a change in their plan as a result of their participation in the idea exploration process (Mod. I / P was not a very common code). More significantly, that change was linked to a shift in the way this group went about solving the problem, and that link was expressed by MS 3 in line 103 (and 105) through a reference to another group’s proposal. As discussed by O’Connor and Michaels
(1996), this act of referencing other students’ ideas while explicating one’s own idea – while common in Japanese classrooms – is rare in American classrooms (pp. 92 – 94). It was also relatively rare in this data corpus with no examples in either Sarah’s or Nancy’s lessons, one example in Sandy’s lessons (presented in the Interactions discussion in her case study), two in Marty’s lessons (one of which will be presented in his case study), and three in Hannah’s lessons. It is significant with regards to the examples in Hannah’s class that two of the three instances involved references to the normative solution to the problem, indicating that either on their own or as a result of the way that Hannah emphasized these solutions (discussed previously), other students recognized something worthwhile in the reasoning behind them.

The discussion in this sub-section will be brought to a close by examining the interactions which developed as Hannah and her students were reviewing the testing which had been done. A key feature of those interactions can be recognized within the following excerpt from Hannah’s period 3 class which picks up part way through the Analyzing the Results segment:


589. FS 17: Yeah, it was the one that (inaudible) was something.  Att. R Give Confirm.

590. Hannah [almost simultaneous to FS 17]: There was one that was good. I think it was this one [pointing to one of the table entries].  Dep. R Give Ana. Res.


592. Hannah: I . . . I don’t know. I just was having you read back how you described them. I think it was this one here [pointing to same entry as in 485].  Dep. R Sup. Reas.

[*Although FS 1 does not finish her thought here, the “but like” and “wait a second” and the tone indicates that she is questioning whatever the description was of the results for the ‘6.54 g.’ sample. This is further supported by FS 1’s turn in 594 below.]
593. FS 17: It was.  
[**This was confirming Hannah’s “... it was this one here.”]

594. FS 1: Yeah, but it was better than the first one — <<it was really, really good.  

595. FS 11: <Yeah, the trial <<the trial 2.  

[***This was in support of FS 1’s statement.]

596. FS 17: It was – I told you it was the best one until [MS 15]’s came along.

597. FS 11: Yeah ... it was a longer flame and it was really bright.  

[****Even though this was a Give Observ., it was done in the context of defending the evaluation.]

598. Hannah: Is this one, [FS 11], do you think? You seem to have really good, um . . .

599. FS 11: Yeah.

600. FS 17: It is – it’s ours.

601. Hannah: Okay, so we’ll just change that one to ‘good.’

By holding up what Hannah is saying in her turns in this excerpt against what a couple of the female students (FS 1 and FS 17) are saying, one can identify the feature of interest – a feature which was first encountered in Sarah’s Interactions discussion. In line 588, FS 1 suggests that one of the ‘6.54 gram’ (equal mass) samples tested gave an “amazing” result. Two lines later, Hannah suggests which one it might have been by pointing to an entry in the class data table (which has been created to keep track of these results) containing the description “good” for that sample. FS 1 is clearly not satisfied with that description, as her oppositional language and tone in line 591 indicates; Hannah defends it in line 592 by noting that what is entered there is what she had been told to write down earlier. This sets off a heated discussion of the issue through the next nine lines; interestingly, that discussion concludes by Hannah changing the entry for another equal-mass sample that was tested from a less positive description
In the end even though Hannah did change a data entry in response to the concern raised by the two female students, she did not change it in accord with the descriptions they gave such as “amazing”, “really, really good”, “the best one until [MS 15’s]” – Hannah merely wrote “good.” In this way Hannah went beyond being a neutral data recorder and into actively participating in the process of analyzing and interpreting the data with the students. This is significant in light of a statement reported in her sketch which represents the mantra she uses with students to express how they should approach data analysis: “Don’t tell me what you think should happen, tell me what this [their data] says did happen.” Hannah knew the equal-mass solution should give a less impressive result than the stoichiometric-mass one and seemed to be trying to make sure the class observations aligned with this expectation. It is also significant as it relates to the extent to which the empirical testability commitment is being supported in these lessons – a point to return to in chapter 5.

*Formalizing the Solution*

In terms of the extent to which students are involved in the development of the scientific explanation, the three teachers whose case studies have been presented so far represent a continuum with Sandy involving students the least, Sarah allowing them an intermediate amount of involvement and Nancy offering them the most. On that continuum, Hannah would fall closest to Sandy as she relegated students’ contributions to responses to slotted questions. This was largely a function of the fact that she had a prepared PowerPoint presentation covering this material which left little room for spontaneously utilizing students’ ideas in constructing the explanation. In fact, as the excerpt below from her period 4 class shows, Hannah even glossed over students’ contributions when they didn’t match the direction her presentation was headed:
274. Hannah: [Brings up two lines on her PP presentation: First reads ‘So why is it 10 for 1/10? Why not 1/10 for 2/10 or 3/10?’; the 2nd reads, ‘And where did the masses come from?’] So, I have a couple of questions: Why ‘1/10 for 1/10’? Why can’t the ratio be like 1/10 for 2/10 or 1/10 for 3/10? Where does this like, <‘If I have 1/10 I need 1/10 come from?

275. Female student right in front of camera: <(Inaudible) they have to be equal.

276. Hannah [to the female student]: What?

277. Same female student: You need, like, a ratio where they’re equal.

278. Hannah: Maybe. Let’s . . . we’ll look at it. And, my other question is, where did the masses come from? Like, why is sulfur ‘32.06’ and zinc is ‘65.4’? Why are they different? What do they mean?

Hannah was looking for an answer to her questions in 274 related to the coefficients in the balanced equation, which would then have served as a segue into the next material on this slide. This is not what she got from the female student, and so she puts off any further discussion of the student’s idea even though it seems relevant to the current conversation. (This student’s statement is not revisited before the lesson ends.)

A distinguishing feature of Hannah’s FtS segment compared to the other three teachers doing the Zn-S reaction lesson was her emphasis on connecting the scientific explanation to the most successful solution, largely to the exclusion of making any such connections to the less successful / unsuccessful solutions. This emphasis is apparent in the way Hannah opened the FtS segment in her period 4 class by reviewing the reasoning given by the group who offered the scientifically-accepted proposal:

257. Hannah: So let’s talk about this before we get into it really. Um, one more time [points at back right corner group] . . . How about one of the girls – can you recap you . . . how you guys did this?

258. [Girls both look at each other]


260. FS 6 [48:25]: We moved the decimal point to the . . . left to get our mass.

261. Hannah: Okay. So what they did is they noticed that the atomic mass for zinc is ‘65.4’ – I’m rounding a little – and so we used ‘6.54’, which is just moving the
decimal place one to the left, right – *one-tenth*. So they did the same thing for sulfur: They noticed that sulfur’s atomic mass is ‘32.06’, so they just moved the decimal point one place and said let’s do ‘3.21’. Okay?

It is also visible in the way Hannah formulated the exit question (which she gave to each class to close out the lesson) in this class:

331. Hannah: Before you leave, you need to paraphrase, okay. Write me a brief paragraph in your notebook explaining why [MS 5]’s, uh, theory, for ‘3.21’ – why was that the best? How’d he figure it out? What . . . why’d it work? [1 sec. pause] And I’ll be around to see it.

It is possible that the reason Hannah did not explicitly attend to tying the scientific explanation to the less successful / unsuccessful solutions is because there were so many alternative proposals offered in her classes as a result of the way she structured the activity. Given that the structure of activity in her lessons was more similar to the one in Marty’s lessons than those in Sarah’s, Sandy’s, and Nancy’s lessons, it will be important to consider how Marty handled this feature of the FtS segment.

*Marty’s Lessons*

*A Sketch of Marty*

The researcher had not known Marty prior to his involvement in this study – the two had been introduced by the physics teacher in Marty’s school who had been the researcher’s physics teacher when the researcher was a student at that school. Marty had a similar level of teaching experience as Nancy, and, like Nancy, taught two different levels of introductory chemistry: honors chemistry for the higher ability students and regular chemistry for the lower ability students. Thus, Marty’s course load also afforded the opportunity to investigate the result of conducting the same MSP lesson with students of two different ability levels (although Marty did not keep the content in the two courses in sync in the manner that Nancy did). As with Nancy, Marty expressed a hesitation towards running this lesson in both classes:
Researcher: So you said – I think this was Friday when I was talking with you – that you would be reluctant to do this kind of thing with the regular chemistry classes. So, can you talk about why that might be problematic from your standpoint?

Marty: Well I think [pause] . . . number one, the quality of the student isn’t . . . I don’t want to say all of them, because some of them should certainly be in that class [the honors chemistry] – but the quality of the student is a little bit lower. Um, behavior is certainly – at least in the afternoon class . . . I mean, if I left them Do that, no one would hear what the next group was saying, because they wouldn’t pay attention. Um, but I think they would be reluctant . . . and, certain groups would be fine, but they’re more the type of kid that would shut down . . .

Researcher: As soon as . . .

Marty: Yeah, they would po- . . . they wouldn’t think about what they actually knew, and what they actually knew and remembered would probably be far less than the other class [honors chem.]. I just think it would kind of turn into [pause] . . . for a good portion of them, it would turn into basically a waste of time and I would end up telling them the answer anyway.

(Interview 3, section D.1)

However, Marty’s resistance to this possibility turned out to be even greater, to the point where the researcher accepted the fact that he would only be willing to carry out the Periodic Trends activity with the two honors sections which he taught.

More than any of the other participants, Marty exuded confidence related to his ability to effectively enact the MSP lesson – a confidence largely born of his strong sense of faith in his own content knowledge. Additionally, Marty recognized a value in the MSP lesson structure, not just in its contributions to classroom learning, but also in the ways that it could potentially parallel the problem-solving process as it occurs in real life (from interview 2, section B.1):

Yeah, I think so [that the MSP structure represents inquiry], um, in that you’re still, you’re still thinking your way through the problem and, you know, in real life, that’s . . . There’s a lot of problems that you try to solve in real life and maybe you don’t get the answer the first time or the second time or the third time. I think there could be some real value to that [engaging students in an MSP lesson] in that, uh, you’re not just working your way through it and getting the answer – you actually have to analyze, ‘Do I have the right answer?’, ‘Why don’t I have the right answer?’, ‘What can I change that’s not going to make the whole
thing brand new?’, ‘Is there bits and pieces that I can modify that would, you know, help me out and get me to the right answer or allow me to do something like that?’

Because of Marty’s self-assuredness related to his ability to run the MSP lesson and because his activity was different from the one used by the other four participants more of the pre-lesson interview / meeting time was devoted to his planned enactment than was the case with the other teachers. Specifically, the focus was on Marty’s vision of the structure of activity and the development of concepts within the lesson. One of the outcomes of placing an emphasis on this was that Marty was able to very clearly lay out his expectations in terms of the kinds of ideas that students might propose in the course of solving the problem (from interview 1, section E.1):

Researcher: Okay. That lesson – does it tend to be a majority of kids [that go down the wrong path] or a smaller percent- ? . . .

Marty: I would say it’s at least half or more that would say that. Because, they usually get the trend in size: As you go down [a group], it’s [the atom] going to get bigger, because you’re adding more [rings], but then they also think, ‘Well, as you go across [a period], you’re adding more [particles], so it’s gotta get bigger.’ And that’s the misconception that a lot of kids make.

It will be important to be cognizant of Marty’s predictions about the points of conceptual difficulty for the students as an examination is made in succeeding sub-sections of the manner in which ideas were explored and the way in which interactions played out in his lessons.

Solution Pathway Maps

As has already been discussed in the sub-section on Hannah’s SPMs, despite the difference in topic, Hannah’s structure of activity in her lessons was more like Marty’s than it was the other three teachers who did the Zn-S reaction lesson. In both Marty’s and Hannah’s lessons, there was a greater percentage of the activity time spent in small-group work than there was in the lessons of Sandy, Sarah, and Nancy. In Marty’s two lessons, this small-group work was encapsulated in two Drawing Models, Predicting, and Explaining Trends segments (one for
the group trend and one for the period trend) and one Conducting the Test segment.

As was also noted in the section on Hannah’s SPMs, her and Marty’s lessons allowed for the greatest number of different proposals to be posited and explored. This was because (1) students worked in their regular lab groups to develop their ideas instead of working in informal groups made up of students seated near them, which likely increased their comfort level in sharing thoughts with each other; (2) all ideas were shared out with the group before any were subjected to critical analysis / further examination (as opposed to the case in the other three classes where the first idea was often immediately examined through the openness and empirical testability commitments before additional ideas were considered); and (3) there was an expectation that all groups would share their ideas out with the whole class (as opposed to a few groups volunteering their ideas in the other three classes). Interestingly, with regard to that last point, in the framing portion of his lessons, Marty had indicated that “I will get a couple of groups to just share with us what their reasoning is” (period 4 transcript, line 35), but, once the Sharing Out sessions actually took place, each group presented their ideas.

Framing the Activity

Perhaps because of the complex nature of the activity he was conducting, Marty allocated the largest amount of time to the Building Up the Problem segment – and therefore to framing the activity – of any of the five teachers: In his period 4 class, this segment lasted nine minutes and in his period 6 class, it lasted eight minutes, 48 seconds. An examination of the dialogue in this segment in the two classes revealed eight elements comprising Marty’s orienting activity: identification of a larger [course] motive (understanding periodic trends); connection to other content in the course; definition of the key term (atomic radius); presentation of the problem; identification of the goal associated with that problem; familiarization with cognitive tools /
resources useful for tackling the problem; description of the structure of the activity; and
discussion of the social process involved in working on the problem.

The largest portion of time in the Building Up the Problem task segment was dedicated to
familiarizing students with the main cognitive tool for solving the problem – the Bohr model of
the atom: in period 4, three minutes, 17 seconds and in period 6, three minutes, 43 seconds.
Further, Marty made it clear just how essential this tool was in accomplishing the activity’s
objective: “So, the reason we’re doing the Bohr Model is because that might lead you in the
correct direction. All right, we’re not just doing the Bohr Model just for fun. That may have
something to do with the trend in size” (period 4 transcript, line 36). It is also important for the
reader to understand that this re-presenting of the Bohr model (the students had encountered it
previously) depicted this tool as a static set of components (protons, neutrons, electrons, and
rings) that could be counted and catalogued.

The other element of Marty’s framing effort worth examining is his discussion of the
social process involved in exploring students’ ideas. To that end, it will be useful to consider
two excerpts addressing this that occur at almost the same points in the two different classes:

Marty: And on a piece of paper, put that order down – whatever you think is
smallest all the way up through in order to the largest – and then, in a couple of
sentences – three or four sentences – write down there why you think that is the
correct order. All right. So you’ve gotta kinda come to a consensus there in your
group and figure that out, all right. Once you’re done with that I am going to –
depending on the amount of time we have – I will get a couple of groups to just
share with us what their reasoning is – right or wrong – and kinda have a . . .
small debate if anyone disagrees. (Pd. 4, line 35)

Vs.

Marty: So, once you have them – and you and your partner agree that you think
that is the correct order smallest to largest – then on the piece of paper – so you’re
going to have to grab a piece of paper before you start this – write down the order,
and then – in about two or three or four sentences – explain to me – or, to
whomever – why you chose that order, all right. Why did you put it in that order?
When you’re done with that, then we’re going to share them with each group, and we’ll kinda come up with an overall trend from each group. (Pd. 6, line 36)

There are two aspects of the social process that these passages share. The first is that a norm of justification (“write down there why”) will be part of this activity, which becomes a central feature of the interactions in the Sharing Out segments. The second is that there is an expectation of the achievement of consensus – i.e. an expectation of cooperation within the groups as they are developing their ideas. What is different between the two excerpts is that, in the period 4 passage, a third aspect is addressed: the possibility of a debate – i.e. the potential for competition between the groups as they present their ideas. Meyer and Woodruff’s (1997a) discussion of these two types of interactions was presented in the Literature Review. It will be important to consider (in the next sub-section) whether either or both kinds of interaction actually were manifested in the two classes.

A final note on this topic related to a point made at the end of the Periodic Trends Lesson sub-section. Because the first day of the activity was a Friday and the activity was finished on a Monday, Marty began day 2 with a re-orientation to key aspects of the activity. However, this segment [Resetting the Investigation] had another critical component to it: Marty reviewed with the classes the use of the data that he and the researcher had decided upon to provide the empirical test of the students’ predictions and explanations. During the period 4 class a problem arose as a result of the fact that students were having a hard time determining the trend across a period from the atomic radii since it did not show a consistent pattern (while the values generally decreased, there were usually a couple of exceptions in each period). This problem was resolved by Marty through the addition of a brief discussion of what is meant by a trend in science during the Resetting the Activity segment in period 6.

The Nature of the Interactions
All of the key interactions around the exploration of ideas which were captured on videotape took place within the three Sharing Out segments in each of Marty’s classes, so the discussion of this topic will center on the action in those three segments. (There were inter- 
interactions of this nature within the Drawing Models, etc. segments, but since these involved small-group discussions, only one group’s data was captured (on audiotape), a limitation to be addressed in chapter 5.) A sample sequence from one of those segments (Sharing Out I, period 4) will serve to exemplify a number of key points about the interactions in Marty’s lessons:

64. Marty: Anyone have the Halogens: fluorine, chlorine, bromine, iodine?  
   Prep. I

65. FS 11: We did.
   Prep. R

   What order – smallest to largest – did you put yours in?  
   Nuc. I Req. I / P

67. FS 11: Um, fluorine, chlorine, bromine, iodine, and astanine [astatine].  
   Nuc. R Give I / P

68. Marty: So, as they went down – bigger or smaller?  
   Dep. I Req. C / E

69. [No response initially]

70. Marty: As you went down . . .?
   Emb. I

71. FS 11 [with FS 12 make a hand gesture indicating they got bigger]:  
   Oh, bigger.  
   Dep. R Give C / E

72. Marty: As they go down, they went bigger.  
   Is that the same as the other group?  
   Dep. F Accept.
   Dep. I Req. C / E

73. FS 11: Yeah.  
   Dep. R Give C / E

74. Marty: Yeah.  
   Why did you say that?  
   Dep. F Accept.

75. FS 11: Uh . . . because the protons increased as we went farther down.  
   Dep. R Give Just.

76. Marty: Okay. They said – not because of orbits – but because the number of protons increased, it got larger.
   Dep. F RU

Before examining specific interactions within this sequence, it is important to recognize the general pattern existing within it, as it was a pattern which was repeated throughout all of the
sequences in the three Sharing Out sessions (except in a few anomalous cases which will be discussed below). Each of these sequences began with an introductory exchange in which the group having a certain family / period of elements was identified. This was followed – in Sharing Out I and II – by an exchange in which the group presented its idea regarding the trend down a family / across a period. In a subsequent dependent exchange in Sharing Out I and II, the group was asked to clarify that prediction by comparing it to what other groups had said (the obvious exception was in the first sequence in these segments). The sequence was then completed by a dependent exchange in which the group offered the justification for their prediction. Most significantly, this final exchange was terminated with a turn in which Marty conducted a re-utterance move 88% of the time (30 out of 34 instances).

One feature of the interactions which is obvious from the description in the previous paragraph is that they were highly structured – really, highly scripted. In at least one case (sequence 28 from the Sharing Out II segment of Marty’s period 6 class), this feature was problematic as it resulted in a breakdown in the conversation:

245. Marty: Last group [referring to the two girls just to the left of camera]. Period? Prep. I
246. FS 2 & FS 3 [in unison]: Potassium. Prep. R
247. Marty: Potassium, calcium – all the way over to krypton. Prep. F
248. FS 2: And we put them in order . . . Nuc. I Give Just.
249. Marty: Smallest to . . . Att. I*
[*This is an Att. – I because Marty was trying to make a Req. I / P initiation.]
250. FS 2: . . . according to how many . . . [Cont. Nuc. – I from 248; Give Just.] [To Marty] You interrupted me! [Smacking her hand on the desk to emphasize this] Emb. I
252. FS 2: . . . how many electrons . . . Now, wait. [Pause] Yeah – how many electrons the element has. They had . . . [Cont. Nuc. – I from 248; Give Just.]
253. Marty: So you’re smallest was? Dep. I Req. I / P
254. FS 2 & FS 3 [in unison]: Potassium.


   Biggest?

256. FS 2: Well, it’s not really the smallest because they all have the same atomic radius . . .

   Things go south in this sequence starting in line 248 when FS 2 breaks the move pattern Marty has established for these Sharing Out segments by giving a justification before she has made clear the trend her group has predicted. Marty tries to restore order in line 249 by beginning a request for proposal initiation, but FS 2 expresses frustration that her turn was interrupted (line 250). Even after the embedded exchange around this faux pas has occurred and FS 2 tries to resume the discussion of her justification, Marty tries to steer her back to the standard pattern by completing a request for proposal (line 253). In this case, it is the form of Marty’s move, not the move itself which causes a disruption: Marty asks which element in the period this group determined to have the smallest radius and the members give a response; the problem is that their actual prediction was that the atomic radii would remain constant across a period because all of the atoms have the same number of electron rings (or energy levels). The confusion caused by the way Marty made his request for proposal and the way FS 2 and FS 3 interpreted it results in the next 26 lines of this sequence being devoted to clearing up this confusion; further, it results in the fact that FS 2 never finishes presenting her justification. This indicates an open question generated by this research: To what extent are highly structured discourse patterns beneficial or detrimental to idea exploration in MSP lessons?

   The next point to be made from the first excerpt is that, while there is a request-give justification pair present in accord with Marty’s norm of justification discussed in the Framing sub-section, there is no request for evaluation present to further support the openness commitment. In fact, only one request evaluation move was identified between the two lessons
Marty conducted. As a result, the only instances in which student ideas (particularly, the explanation of the predicted trends) were critically analyzed by other students in an observable form were when students interrupted the standard discourse pattern in the Sharing Out sequences. The most significant example of this occurred in Marty’s period 6 class and involved the same student at the center of the discussion in the last excerpt:

190. Marty: What’s your reason?
191. FS 7: Well, they stayed the same, they just increased in the number of protons and neutrons.
192. Marty: So what stayed the same?
193. FS 7: The number . . .
194. FS 8: The number of rings.
195. FS 7: Yeah.
196. Marty: The number of rings stayed the same;
   they increased the number of . . .
197. FS 7: Protons.
199. FS 7: Neutrons.
201. FS 7: And sometimes they increased in electrons, but sometimes they stayed the same.
202. Marty: Okay, sometimes they increased the number of electrons and sometimes they stayed the same. [About a 3 sec. pause] So that is . . .
203. FS 2: Wait, I’m confused.
204. Unknown female student: So am I.
205. Marty: What are you confused about?
206. FS 2 [directed at Marty]: Isn’t the number of protons and the number of electrons the same?
207. Marty: Yes.
208. FS 2 [directed at Marty]: So how is it that the protons can increase but the electrons don’t?
209. FS 7 [responding to this]: Okay, then it was the neutrons that stayed the same.

In the first exchange of this excerpt, the dialogue is following the typical pattern in these sequences with a request-give-justification dependent exchange (which followed a request-give-proposal nuclear exchange not included in the excerpt). There is a modification in the typical pattern after this that results from the ambiguous use of two different “they’s” in line 191 which requires several turns (lines 192 – 201) devoted to clarifying the referents of those pronouns. At this point, things are set to return to normal as it appears in line 202 that Marty is about to conduct his standard follow-up move in which he will close out this sequence and prepare to initiate a new sequence. However, just as he begins such an utterance (“So that is . . .”), FS 2 interrupts him and expresses confusion. This confusion stemmed from an inaccuracy in FS 7’s justification and, as a result of expressing it (in lines 206 and 208), she causes FS 7 to modify this part of her justification. The significance of this is that there were a limited number of cases of students modifying either their ideas or their proposals as a result of concerns raised by other participants in the dialogue, and this one only occurred because FS 2 was outspoken enough to interrupt the typical pattern of dialogue in these sequences and air such a concern. (In this sense there is a parallel here with Sarah’s period 5B class where it was only because of the outspoken nature of FS 5 that some of the unique interactions took place in that lesson.)

In preparation for the next point to be discussed, the reader is asked to look back at Marty’s turn in line 76 of the first excerpt. In this turn, Marty employs a re-utterance move, which he used more than any other teacher in this study (30 times in the two lessons). However, it is not just the frequency of his use of this move that is important; it is actually the content of it which is most significant. In the example in line 76, Marty’s parenthetical of “not because of orbits” was a reference to the justification given by the previous group; i.e. he was using this re-
utterance to hold up the difference between the explanations for the predicted trends given by the first two groups to present. Marty consistently made such comparisons between the justifications offered by different groups through the vehicle of these RU moves. Another example of this use of the RU by Marty to compare the ideas presented by different groups comes from the first Sharing Out segment in period 6:

117. MS 10: Ours was, it was due to the atomic mass which [makes hand gesture] makes [pause] . . . makes it have protons and neutrons . . . The higher the number of the atomic mass, the more protons it has . . .

118. Marty: Okay.

So this group said the same thing, except they said, as you go down, the mass got larger . . . which happens to be true. So kind of a little bit of what both [previous] groups said. You said, because mass is protons and neutrons – well it [mass] got larger, so the size got larger.

The reason for including this second example is that, whereas the comparison in Marty’s line 76 RU from excerpt one expressed the differences between two different groups’ ideas, the comparison in the RU in line 118 above indicates similarities between three different groups’ ideas. It is worth examining what the two previous ideas were then: In line 68, the first group to present in this segment had said, “Okay, the more rings they have, the higher the atomic num-

. . . or, the atomic radius will be”, and in line 91, the second group to present had suggested, “They had more rings, protons, neutrons, and electrons.” Although Marty has treated these three ideas (including MS 10’s justification in line 117) as similar through his re-utterance in line 118, there are in fact subtle but significant differences: The first group’s idea (“more rings”) is focused on the distance dimension of size; the second group’s idea seems to be based on an ontology which dictates that having more things (“rings, protons, neutrons, and electrons”) means an object must be bigger; and the third group’s idea (“atomic mass”) emphasizes the mass dimension of size.
The point being made here is that re-utterance moves such as the one included in the excerpt above began to blur the distinctions between different ideas offered by students and prevented those differences from becoming points of discussion in this activity. This happened in both of Marty’s lessons. It is likely because of this that the potential debate which Marty had suggested might occur during the Building Up the Problem segment in his period 4 class never materialized. In general, the lack of requests for evaluation noted previously and the manner in which re-utterance moves discounted the diversity in students’ ideas meant that the kind of competitive inter-group interactions discussed by Meyers and Woodruff (1997a) were not found in either of Marty’s MSP enactments.

There was an interesting feature of Marty’s terminal follow-up move in each sequence which was only observed in his period 6 class. It can be identified by comparing his last turn in each of the two excerpts provided below:

121. Marty: Okay. Instead of going through all of them, do you have the same exact trend as you went down – they got larger? Nuc. I Req. I / P
122. FS 11: Yep. Nuc. R Give I / P
    Why?
124. FS 11: We figured that as long as electron rings are the same size, then more rings equals a bigger atom. Dep. R Give Just.
125. Marty: Okay. So as long as the rings are all the same size, the more rings, the larger the atom – or, the more orbits, the larger the atom. Dep. F Accept. // RU
    Vs.
160. Marty: This group said that each element – lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, neon – are all the same. Nuc. F RU
161. MS 10: Well, because they have the same atomic radius, because they all have the same number of rings. Dep. R Give Just.
162. Marty: They say that they all have the same radius because they have the same number of rings.

Sounds logical.

[*Not coded as RU because nothing was changed from what MS 10 said, and no comparison to other groups’ ideas was made.]

The reader should notice that there was something present in the second excerpt – which was taken from a sequence in the Sharing Out II segment – which was absent in the first excerpt – which was taken from a sequence in the Sharing Out I segment: an evaluation of the justification (“Seems logical”). This same evaluation or one of a similar nature was found in four of the six sequences in the Sharing Out II segment (the two in which such an evaluation wasn’t present involved cases of breakdowns in the discourse pattern) and none of the sequences in the Sharing Out I segment in Marty’s period 6 class. Given that the Sharing Out II segment was focused on the trend across a period – which, as was discussed in his sketch, was a part of the activity where Marty fully expected students to make incorrect predictions and provide invalid justifications – and that the Sharing Out I segment was concerned with the trend down a family – which was a part of the activity where Marty anticipated that students would get both the trend and explanation correct – it is possible that this difference in the nature of the follow-up move was a function of Marty’s expectations going into the lesson (a point to be revisited in chapter 5).

The final feature of the interactions in Marty’s lessons to discuss requires the presentation of two excerpts from his period 6 class (the first of which will set the stage for the FtS discussion), which were separated by two sequences and which both came from the Sharing Out III segment:

303. Marty: So I’m going to ask each group for just a brief explanation of why the things get smaller from left to right. [Points to back middle lab group]

304. MS 10: Gravitational pull.
305. Marty: This group says *gravitational pull.*

Why?

306. MS 10: Because as the . . .

307. MS 1: Nucleus gets larger . . .

[*MS 1 is helping MS 10 build up the explanation.*]

308. MS 10: . . . nucleus gets larger, the gravitation brings all the
electrons in farther [uses hand gestures to represent these two
effects], and increases . . . or, decreases the . . . the . . .
it’s radius.

[Cont. Dep. – R from 306; *Give Just.*]

And:

332. [Marty points to front middle lab group]

333. FS 13: Well we have an answer, but the answer’s wrong,
so do you want to hear that answer?

334. Marty: I wanna hear it anyway –
how do you know it’s wrong?

335. FS 13: Okay. Because . . .

336. FS 12: Because it’s the opposite of what they said [pointing to
back middle lab group] and what they said made sense.

In the first excerpt, MS 10 provides one of the more interesting explanations for the trend
across a period – an explanation closely aligned with the accepted scientific version. In the
second extract (which occurs three sequences later), FS 13 immediately indicates that her
group’s answer is wrong (line 333) – and three lines later supports that assertion by allusion to
the explanation given by MS 10. This event – of one student / group referencing another’s ideas
– was introduced in the *Interactions* discussion in Hannah’s case study. There, it was noted how
rare this event was – including in Marty’s enactments. The only two examples of this kind of
interaction in Marty’s lessons – this one and one found in the period 4 class – took place in the
Sharing Out III segment, when the students faced the most challenging part of the activity.

Given its potential for supporting the openness commitment and yet the unfortunate fact of its
sporadic occurrence in the lessons analyzed, it will be important in chapter 5 to try to identify conditions which may be more conducive to this act of students referencing each other’s ideas (e.g. the fact that the most paradigmatic instances of it took place in Hannah’s and Marty’s lessons which both had a similar structure of activity).

**Formalizing the Solution**

During this sub-section of the case studies with the first three teachers (Sandy, Sarah, and Nancy), it was noted that each of them explicitly made connections between the scientific explanation being developed in the FtS segment and both the tenable and untenable solutions which students had proposed. It was further pointed out that these three teachers varied in the extent to which they involved students in building up these associations, with Sandy giving the least amount of opportunity for student participation and Nancy giving the greatest opportunity.

Within the FtS discussion in Hannah’s case study, it was indicated that she only connected the scientific explanation to the tenable solution (largely through the exit question) in each of her classes. At the same time, the reader was reminded that Hannah had a different structure of activity in her lessons, and while no causal connection between those two facts was being suggested, it seemed worth keeping this in mind going into the FtS discussion of Marty’s lessons since he had a structure of activity very similar to Hannah’s.

An analysis of the FtS segment in Marty’s two lessons showed that he also did not tie the scientific explanation into the untenable proposals made by students. Interestingly, Marty laid a perfect foundation for generating such associations at the beginning of the third Sharing Out session (the one that took place after the students completed the ‘empirical test’ of their data), but only in the period 4 class:

231. Marty: For the other trend – for a period – we all agreed – or, not me – but, you all agreed that, as you went from left to right, the things would get larger. And
everyone was pretty certain about that. And your reasons somewhat varied but basically ‘more protons, more electrons – the thing has to get bigger.’ And that makes sense for things that we deal with in everyday life. If you add things onto something, it has to get bigger – that’s the way we think about things. But you should have all found that that was not the trend. The trend is actually the exact opposite: They’re smallest – or smaller – on the right, and they get bigger as you go to the left.

While Marty never built on this any further, what he did try to do in both classes was to navigate through the process of developing the scientific explanation by using the most tenable student ideas (related to accounting for the trend across a period) as a starting point. This excerpt from the beginning of the FtS segment in period 6 is representative of that situation:

70. Marty: A couple of things: The trend is that way for . . . kind of a mix of two different groups. They [group to left of camera] said more electrons makes more negative . . . true, right?

71. A couple of students: Yes.

72. Marty: More protons also, right? So it makes more positive. So if you have more plusses and more minuses – although it’s not because specifically of gravity [reference to what back middle lab group said], because the mass of those things is so small that it probably wouldn’t affect it . . . But, you [referring to that group] have the right idea, because the formula to figure out gravity – Newton’s Law of Universal Gravitation – is exactly like Coulomb’s Law – except it deals with two different things. So gravity – in connection with Coulomb’s Law, which says the amount of force and distance between them attracts things – goes with theirs [group who talked about greater amount of negative charge].

The literature in science education has described the importance of trying to work off of students’ ideas in constructing scientific principles (Dhindsa & Anderson, 2004; Ryder & Leach, 2008). This is clearly what Marty tried to do in the example just cited by taking the proposal made by one group – of accounting for the trend across a period in terms of gravitational pull (see excerpt in Interactions discussion) – and linking it to the force that is responsible for this trend – electromagnetism as encapsulated in Coulomb’s Law. However, there are challenges in building such bridges, often related to making sure key points don’t get lost in translation. That such a loss did occur for at least one student is evident in these two passages from different
points in the interview with Sally (whom Marty identified as an average student in this class):

[From B.2 in response to a question concerning the trend down a family]

Sally: Okay. As you went down, they got an extra ring for the electrons. And, as you went down, the gravitational pull got weaker, because as the electrons got farther, that wasn’t . . . they weren’t as close so that the magnetic . . . well, not magnetic, but it’s like a magnet . . . the farther away, the weaker the bond is. So, that’s kind of how I explained it.

And . . .

[From B.3 in response to a question concerning the trend across a period]

Sally: I think it did . . . it had something to do with the gravity pull . . . I think. And it being . . . having more electrons, it made it smaller. Yeah, I remember it had something to do with both of them, but I’m not quite sure what it is.

It may be that the complexity of the MSP lesson structure – with all of the ideas swirling around – may make it even more difficult to effectively build the scientific explanation off of students’ contributions. In chapter 5 it will be important to revisit this issue and consider what kinds of interactions and what structure of the activity might lend themselves best to creating such connections.

A General Overview of the Discourse Data

With the qualitative data regarding the patterns of interactions and the manner in which certain discourse moves presented in the second section of this chapter as appropriate background, it is now possible to bring the Presentation of Data to a close by examining some quantitative information. This quantitative information will be condensed into the two pairs of tables which follow, with a discussion between the two pairs designed to focus the reader on key bits of numerical data. The format of the four tables is in accord with the point made previously that it will be the most useful to look at data across the first two lessons for each teacher, and then examine the data for the additional lessons conducted by Sandy, Sarah, and Hannah.
Table 7: Frequency of Discourse Moves in 1st Two Lessons for Each Teacher Participant

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<td>0</td>
<td></td>
</tr>
<tr>
<td>Give Observ.</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Req. Ana. Res.</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Give Ana. Res.</td>
<td>18</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>RU</td>
<td>4</td>
<td>2</td>
<td>16</td>
<td>14</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 8: Frequency of Discourse Moves in Remaining Lessons for Each Teacher Participant

<table>
<thead>
<tr>
<th>Move</th>
<th>Teacher and Lesson</th>
<th>Hannah Pd. 3</th>
<th>Sandy Pd. 7</th>
<th>Sarah Pd. 5B</th>
<th>Sarah Pd. 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Req. I/P</td>
<td></td>
<td>20</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Give I/P</td>
<td></td>
<td>17</td>
<td>9</td>
<td>11</td>
<td>3</td>
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<tr>
<td>Req. Alt.</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Give Alt.</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Req. Re-Expl.</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Give Re-Expl.</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Req. Just.</td>
<td></td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Give Just.</td>
<td></td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Req. C/E</td>
<td></td>
<td>17</td>
<td>8</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Give C/E</td>
<td></td>
<td>32</td>
<td>12</td>
<td>27</td>
<td>16</td>
</tr>
<tr>
<td>Req. Eval.</td>
<td></td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Sup. I/P</td>
<td></td>
<td>6</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Mod. I/P</td>
<td></td>
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<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ref. I/P</td>
<td></td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Sup. Reas.</td>
<td></td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ref. Reas.</td>
<td></td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Req. Pred.</td>
<td></td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Give Pred.</td>
<td></td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Req. Observ.</td>
<td></td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Give Observ.</td>
<td></td>
<td>18</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Req. Ana. Res.</td>
<td></td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Give Ana. Res.</td>
<td></td>
<td>16</td>
<td>1</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>RU</td>
<td></td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>
There seems to be little validity in making quantitative comparisons between teachers related to the frequency with which certain discourse moves were employed. There are two reasons for this. The first is that there were differences in the amount of time devoted to the two activities in each classroom: Hannah’s, Marty’s, and Nancy’s lessons all spanned two class periods; Sandy’s and Sarah’s lessons were completed in a single period. The second is that there were differences in the structure of activity in the lessons which translated into differences in the propensity for using a certain move. For instance, because of the structure of activity found in Hannah’s and Marty’s lessons, it was inevitable that there would be a higher frequency of use of request // give idea / proposal moves in their enactments than in those of the other three teachers.

There are, though, still a couple of valuable things which can be gleaned from the data in this initial pair of tables. The first is that the request clarification / elaboration (167 instances or 5.6% of coded data) and the give clarification / elaboration (234 instances or 7.9% of coded data) moves – which both help enhance the level of mutual understanding in the classroom – were among the most frequently identified codes. However, another pair of moves which could help support this commitment – request for // give re-explanation – was only used by two teachers (Hannah and Sarah) and only in very limited applications (5 instances of each in the coded data – and, for both teachers, only in conjunction with the normative solution).

In terms of the expansion commitment, the request alternatives move is a key supplement to the request idea / proposal as a means to insure that the greatest number of ideas receive consideration. This move was only used 7 times in the entire corpus of data, and while this partially reflects the fact that there was no need for it in Hannah’s and Marty’s lessons, it also indicates it was under-utilized in the enactments of the other three teachers. Moreover, as was noted in the cases studies of Sandy, Sarah, and Nancy, there was an issue regarding where it was
placed relative to other moves such as request justification which may have affected the way in which students responded to its utilization.

The emphasis placed by most of the teachers on having students provide a rationale for their ideas was reflected in the extent to which they employed the request for justification move (86 instances; 2.9% of the coded data), which has implications related to the openness commitment. The other moves which are associated with this commitment are support // modify // refute idea / proposal and support // refute reasoning and there are a couple of interesting pieces of data related to the use of these moves. The first – which can be ascertained from the data presented in the tables above – is that there were far more examples of support // modify // refute idea / proposal (109; 3.7% of coded data) then there were of support // refute reasoning (48; 1.6% of coded data). The significance of this will be addressed in the next chapter.

The second requires the reader to examine the second pair of tables and to note – by moving across the second data row in each table – that of the 157 total instances across the five code categories related to critical evaluation of ideas / reasoning, 41 (26%) of the cases were moves conducted by teachers. This data makes it clear that students were engaging in these discourse practices even less than it initially appears.

A similar point can be made related to the way the empirical testability commitment was maintained in this data corpus. Inspection of the first pair of tables shows that there were 151 total instances of give a prediction // observation // analysis of results; consideration of the second pair of tables indicates that 15 (10%) of those were moves conducted by teachers. This speaks to the point made a couple of times throughout section two of this chapter about the extent to which teachers ended up becoming participants in this process.
Table 9: Frequency of Additional Discourse Features in 1st Two Lessons for Each Teacher Participant

<table>
<thead>
<tr>
<th>Feature</th>
<th>Teacher and Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instances of lack of uptake of ideas, elab., eval.</td>
<td>0</td>
</tr>
<tr>
<td>Instances of teachers conducting Sup.//Mod.//Ref. I/P or Sup. //Ref. Reas.</td>
<td>4</td>
</tr>
<tr>
<td>Instances of teachers conducting Give Pred. // Observ. // Ana. Res.</td>
<td>1</td>
</tr>
<tr>
<td># of S-S interactions in whole-group act. segments</td>
<td>3</td>
</tr>
<tr>
<td># of references to other students’ ideas when explaining own idea</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 10: Frequency of Additional Discourse Features in Remaining Lessons for Each Teacher Participant

<table>
<thead>
<tr>
<th>Feature</th>
<th>Teacher and Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hannah Pd. 3</td>
</tr>
<tr>
<td>Instances of lack of uptake of ideas, elab., eval.</td>
<td>0</td>
</tr>
<tr>
<td>Instances of teachers conducting Sup.//Mod./Ref. I/P or Sup. //Ref. Reas.</td>
<td>9</td>
</tr>
<tr>
<td>Instances of teachers conducting Give Pred. // Observ. // Ana. Res.</td>
<td>5</td>
</tr>
<tr>
<td># of S-S interactions in whole-group act. segments</td>
<td>12</td>
</tr>
<tr>
<td># of references to other students’ ideas when explaining own idea</td>
<td>2</td>
</tr>
</tbody>
</table>

Finally, the data in the second pair of tables shows how central the teacher was to the interactions by representing the minimal number of direct student-student interactions in most lessons (with the exception of Hannah’s period 3 class) and the limited instances of students directly referencing each other’s ideas when offering their proposals / reasoning. It is also significant that many of the student-student interactions which did occur were side conversations that never received uptake in the main dialogue of the class. In chapter 5 it will be important to consider the implications of these various facts in relation to the extent to which the principles of progressive discourse were maintained within these MSP enactments.
Discussion of Findings and Implications

Addressing what he identifies as the two levels of teaching, Wells (1999) provides the following depiction of the practice of teaching:

In this initiating role [with regard to classroom activities], the teacher is . . . responsible for leading whole class sessions, in which themes and activities are introduced, students presented with appropriately pitched challenges, expectations made clear and, in due course, both processes and outcomes evaluated and reflected upon . . . Having created the setting and provided the challenge, the teacher observes how students take it up, both individually and collectively, and acts to assist them in whatever ways seem most appropriate to achieve the goals that have been negotiated. (p. 243)

In many ways the goal of this research was to investigate a vehicle – the MSP lesson structure – through which teachers could realize the vision presented in this description by Wells. That goal was captured in the research question that guided this study: What is the nature of the interactions that occur during Multiple Solution Pathway (MSP) lessons and how are those interactions related to the structure of activity and the way in which ideas are explored within those lessons? The data for answering that question came from five teachers (Hannah, Marty, Nancy, Sandy, and Sarah) conducting fourteen different enactments using two different activities (the Zn-S reaction lesson and the Periodic Trends lesson) of the MSP structure as these participating teachers understood it (as well as the interview data collected from teachers and students before and after those enactments). In the last chapter, sample data representing the way those instantiations played out and showing the manner in which the interactions within each were related to the structure of activity and the exploration of ideas was presented.

In this chapter, findings from the data will be discussed through the lens of the theoretical framework laid out in the Introduction. By way of a preview, what those findings will indicate is that no single enactment realized the ‘ideal’ MSP lesson structure in terms of completely fulfilling the notion of progressive discourse. However, each enactment had features that
supported some or all of the commitments of progressive discourse – thus pointing in the direction of that ideal in practice – and so the findings will be concerned with conveying broad themes and patterns in those features – along with identifying broad themes and patterns related to features that worked in opposition to the principles of progressive discourse (section 1 of this chapter). Once those findings have been laid out, it will be possible to describe a small set of pedagogical implications which can be derived from them (section 2). Those implications will need to be tempered by the recognition of limitations to the current study (section 3). Finally, ways to overcome those limitations as well as ways to address questions / issues which arose during this inquiry will be discussed in the form of directions for future research (section 4).

Findings

The answer to the research question can be summarized in two major assertions, each of which will be decomposed into a couple of key points which will clarify the scope of the findings to which the assertion applies.

Assertion #1: The set of enactments examined can be categorized into two large groups based on the way in which the exploration of ideas was structured, which strongly influenced the interactions around those ideas and the extent to which the commitments of progressive discourse were supported.

Looking at the lessons analyzed in this study at a macro level, there were two broad patterns of interactions which were manifestations of the structures for idea exploration the teachers made available to the students. The first, which will be identified as the Constrained Idea Exploration Structure (CIES), was represented by the enactments captured in the classrooms of Nancy, Sandy, and Sarah; the second, which will be identified as the Expansive Idea Exploration Structure (EIES), was illustrated by the instantiations from Hannah’s and Marty’s
classrooms. The way in which those idea exploration structures influenced the interactions and support of the commitments of progressive discourse will be delineated in the points that follow.

1. The two idea exploration structures differed in the opportunities they afforded for interactions related to the expansion and openness commitments, putting these two in opposition.

As was pointed out in chapter 4, in the lessons following the CIES pattern (those of Nancy, Sandy, and Sarah), a smaller percentage of time was spent in small-group discussions (usually only in the Idea Generation segments); when such discussions did occur, they normally were between students sitting next to each other and the teacher usually did not interact with students during them. In the lessons following the EIES pattern (those of Hannah and Marty), a higher percentage of time was spent in small-group discussions; when such discussions took place, they were between members of lab groups and the teachers regularly interacted with these groups. The overall result of these differences in the structure of idea exploration and the interaction patterns was that the expansion and openness commitments were not given equal support, with one being given precedence of the other in each of the two idea exploration structures.

Within the CIES pattern found in the lessons of Nancy, Sandy, and Sarah, only a limited number of ideas were proffered and examined: 2 and 3 in Nancy’s two classes; 2, 2, and 3 in Sandy’s three classes; and 2 in each of Sarah’s classes. The proposals which were made were usually subjected to some amount of critical analysis in the form of requests for justification or requests for evaluation, with the teacher controlling the depth of this analysis. Further, there were several examples from each of these teachers’ enactments in which lengthy discussions occurred around a given proposal. This description indicates that the openness commitment was given greater attention at the expense of the expansion commitment in this pattern.
By comparison, in the EIES pattern found in the lessons of Hannah and Marty, each group generated and presented their own proposal, which meant at least six proposals were examined in each of their lessons. The extent of the critical analysis of any of these ideas was usually a single request-give justification pair; exceptions to this involved either anomalies in the discourse pattern (such as the excerpt presented in chapter 4 involving the outspoken FS 2 in Marty’s period 6 class) or evaluations made in small-group segments of the activity which were generally not shared with the larger group. Likewise, lengthy discussions around a particular proposal were the exception, not the norm. This depiction suggests that the expansion commitment was afforded more consideration than the openness commitment in this pattern.

Within the two general patterns, there were some variations related to the presence of specific task segments which influenced the way students explored ideas. One example of this comes from Sarah’s lessons: She was the only teacher to have the Sharing Out Prior Knowledge task segment and it was within this portion of the lesson in her period 5B class that the debate which eventually led to the two different student proposals began. If this task segment had been absent, it is likely that FS 5 would not have developed her equal-mass proposal; thus its presence helped to sustain the expansion commitment (which, as noted above, was otherwise not well supported in Sarah’s lessons).

A second example of this influence comes from Hannah’s enactments; she also had a task segment unique to her lessons: Revising the Plan. While there was generally not any evaluation of students’ proposals in the Sharing Out segments of Hannah’s lessons, the opportunity for such evaluations did arise in the Revising the Plan segments (as well as in her Testing Proposals segments). This somewhat mitigated the lack of attention given to the openness commitment in the Sharing Out segments. However, as was pointed out in chapter 4, this shift in where the
openness commitment was most strongly upheld was not without its drawbacks: As compared to the Sharing Out segments, the Revising the Plan segments involved small-group discussions and so any concerns which may have been raised about a particular proposal were generally not communicated to the larger community of inquirers.

2. The CIES and EIES patterns differed in terms of the implicit view of trial-and-error they conveyed to the students.

The differences between two patterns of idea exploration may have implied two different views of trial-and-error – and students may have connected these two different views with both classroom science inquiry as well as disciplinary science inquiry. Further, these differences in the way trial-and-error was represented may have influenced which possible interactions the students saw as being available as ideas were being explored. The view of trial-and-error communicated by the pattern found in Hannah’s and Marty’s lessons is illustrated by this excerpt from the interview with Leanne from Hannah’s period 3 class, which came at the point at which the interviewer was trying to gain insight into her views on the role of mistakes in science (A.1):

Leanne: I think science is about mistakes, because . . .
Researcher: It is? That’s interesting.
Leanne: I mean, you have to make a lot of mistakes to get to the right answer or whatever – like what we did in class today. We made all of those different . . . I guess theories and stuff – and we tested them all and they were all mistakes until we got to the one. So, I mean, I think scientists – as smart as they are – they make, well, a lot of mistakes – to get to the final answer.
Researcher: Okay, so it’s this testing process . . .
Leanne: Yeah.
Researcher: . . . and sometimes ideas . . .
Leanne: It’s like math.
Researcher: It’s like . . . how’s it like math in that sense?
Leanne: Well, I guess, I mean, my element- . . . I’m doing elementary functions right now and the one – the one thing you do, you just have to keep testing
numbers until you find the one that works . . .

Researcher: Okay.

Leanne: . . . so, I mean, it’s kind of testing theories until you find the one that works.

Researcher: Okay. Do you think it’s just kind of random testing or . . .?

Leanne: No [said definitively]. It’s not random.

Researcher: Okay, so how do they . . .?

Leanne: Like our – our experiment, there are different theories. Like, one was [pause] . . . like one could be like double it – like double the thing – or, like half of it or . . . Like there are different theories that you test out until you find out [which one works].

Researcher: Okay, so what just happened in class – you thought that represents kind of the way science really would work?

Leanne: Yeah.

In Hannah’s class, the pattern was such that all proposals were tested regardless of the strength of their justifications. The only critical analysis of the proposals and their justifications took place in the small-group Testing the Proposals / Revising the Plans segments. Thus the experience of the students in this class was one of uncritically testing all of the ideas until the class found “the one that worked.” The excerpt from Leanne’s interview suggests that she has assimilated this experience from Hannah’s class into her view of how disciplinary science works – equating proposals and hypotheses with scientific theories and random testing with a reasoned approach to empirical analysis.

The view expressed in the above excerpt should be compared to the perspective of the scientific process conveyed by Tim – a member of Nancy’s period 6 class – in the following exchange (from B.2 when the researcher was reviewing some proposals with him):

Tim: Yeah. He [another student] decided he wanted to use double the sulfur which turned out to be like thirteen point some- . . . ‘13.08’ or something like that. And then a girl that was back there, she said ‘3.2’ because [the teacher] told us to look at the periodic table and figure it out from there. And she saw that zinc was ‘65.4’ and then sulfur was ‘32. whatever’ and she came up with ‘3.2’ because we
had ‘6.5’ [grams of zinc given].

Researcher: Okay, so you had these two different ideas: You had a guy who said ‘13’ and a girl who says ‘3.2’. Um, do you remember having a thought on which one made more sense to you at that time?

Tim: I’d go with probably her idea because there was more scientific logic than just like ‘double it up and see what happens.’ It’s like, she had a scientific theory behind it I guess you would say.

In Nancy’s class, the pattern was such that only those proposals which had endured serious critical examination (usually by Nancy herself) were allowed to pass onto the testing stage. This led to certain proposals being deemed more worthy for further consideration than others. Tim’s statements – particularly in the last turn of the excerpt – indicated his awareness of the differences in the strengths of the justifications for the different proposals offered. While he, too, exhibited confusion over the meaning of theory, it is clear that his view of this term included some element of reasoning. Related to this, later (D.1) he would suggest that it was okay not to test an idea (such as the ‘13 gram’ proposal he discusses in the excerpt above) if it had weaker reasoning to support it (rather than to use a “guess and check” approach).

The difference in the way these two students experienced their respective MSP lessons relates to a distinction alluded to in the following passage from van Oers (1984):

The history of science shows that, man demonstrates his rationality not by a commitment to fixed ideas, stereotyped procedures or immutable concepts (however successful they may be or however high a scientific status may be ascribed to them), but by the manner in which he corrects and improves those ideas, concepts and procedures. Scientific thinking must be characterized by its art of reasoning, its kind of problem-solving, its way of looking for and dealing with mistakes in the ideas, procedures and concepts that in the history of science have been brought forward. Scientific thinking is, in fact, sophisticated trial-and-error. (p. 233)

In this chapter, van Oers differentiates between random trial-and-error – of which Leanne’s description of both her MSP experience and science in her excerpt was indicative – and sophisticated trial-and-error – of which Tim’s discussion of his MSP experience was
representative. In order that students be aided in properly understanding this difference in particular, and the true nature of science (Kosso, 2009; Wong & Hodson, 2009) in general, MSP lessons need to be structured in such a way as to properly balance the desire to consider as many ideas as possible (the expansion commitment) with the need to critically evaluate ideas to determine their merit (the openness commitment).

3. The way the patterns supported / inhibited the expansion and openness commitment was mirrored by certain discourse moves employed by the teachers.

It was noted in point 1 that the CEIS pattern gave less attention to the expansion commitment. Exacerbating this situation was the fact that the teachers whose lessons followed this pattern either did not employ moves such as request for alternatives (as for example in both of Nancy’s classes during the Sharing Out Initial Proposals segment) or utilized moves such as that and request for evaluation in ways that were not conducive to the consideration of additional proposals (examples of this from Sandy’s and Sarah’s lesson were discussed in chapter 4). Related to this, Nancy’s practice of not exhibiting uptake of students’ input if that input was given before (1) she had formally announced the problem to which the ideas pertained and (2) students had been given time to reflect on the problem produced the unintended consequence that some contributions were never pursued: Five of the eleven proposals / evaluations which did not receive this uptake initially were never reintroduced into the conversation, thus further undermining the expansion commitment (and the openness commitment in the case of the evaluations).

It was also noted in point 1 that the EIES interaction pattern gave less attention to the openness commitment. Exacerbating this situation in Marty’s enactments was the way he utilized the re-utterance move – a move he used far more frequently than any teacher in this study (30 times vs. 13 for the next highest individual). In chapter 4, it was pointed out that most
of these instances were found within the terminal follow-up move in the sequences during the Sharing Out segments. Their function in this position was generally to compare and contrast justifications offered by different groups. The most critical aspect of this situation is that Marty often minimized what in some cases were fundamental differences between these justifications. Further, by making these assessments himself, Marty was taking this responsibility out of the hands of the students. This set of circumstances indicates that this particular application of the re-utterance move may have inhibited the proper realization of the openness commitment.

4. The CIES and EIES patterns and associated interactions produced variations in the way the normative scientific explanation was connected to both tenable and untenable solutions.

In point 1 the influence of the two different patterns and associated interactions on the level of support given to the expansion and openness commitments was discussed. In a similar vein, data presented in the Formalizing the Solution sub-sections of chapter 4 indicated that there was a relationship between these patterns and the extent to which the scientific explanation was connected to different proposals. All of the teachers discussed how the scientific explanation could account for the [most] tenable solution in this segment of the activity. However, while Nancy, Sandy, and Sarah also made the ties between the scientific explanation and the untenable solution(s) explicit, Hannah and Marty did not do this. It is not being suggested that there is a causal link between the patterns identified and whether the untenable solution(s) is (are) considered in discussing the scientific explanation – that the choice of the pattern determines what kinds of connections to students’ ideas can be made. Certainly, there could be other explanations for this relationship (e.g. that Hannah and Marty consciously chose to only tie the scientific account to the tenable solution because they didn’t want to overwhelm their students by
addressing all of the ideas explored). Nonetheless, it is possible that the pattern contributes to this circumstance – particularly given the fact that so many more ideas were explored in the one found on Hannah’s and Marty’s lessons – and so such correspondences must be recognized.

Assertion #2: The manner in which interactions and idea exploration were structured in these lessons resulted in particular aspects of scientific thinking being implicitly or explicitly emphasized by individual teachers.

1. The way teachers oriented students to key cognitive tools produced interactions which supported idea exploration in some case and constrained it in others.

Given the complicated nature of the MSP lesson structure, one could have predicted that the content of the [largely monologic] discourse in the Building Up the Problem segments in each enactment would be critical in terms of the way it framed the students’ movement through the problem space of the activity; data presented in chapter 4 showed that this prediction was accurate. Marty’s orienting action was noted to be the most thorough among the five teachers; the numerous elements present in it were delineated in the discussion of his enactments. This translated into a very efficient exploration of the problem space by Marty’s students, with the only difficulties encountered being how to apply the Bohr model properly to elements on the right side of the periodic table in rows 4 through 6 (a difficulty experienced in his period 4 class but overcome by a modification of the framing discussion in period 6).

Hannah’s orienting action was supported by a video she showed students – which served as an important referent related to the empirical testing of students’ proposals – and by a hand-out which served as an exemplar in terms of guiding the complex cognitive activity of generating, communicating, and justifying proposals (although it did not support the openness commitment relative to the critical evaluation of those proposals). Her hand-out was significant
in an undesirable way as a parameter she set within it (the 15-gram sulfur limit) unexpectedly produced a constraint in the way students explored the problem space.

Neither Hannah’s hand-out nor the presentation that was also part of her framing discussion made the two key cognitive tools (the chemical equation and the periodic table) needed to move through the problem space salient and, concomitantly, few students in any of her classes utilized those tools. By comparison, Sandy made the one tool – the chemical equation – extremely salient and students readily accessed it in generating their proposals.

Both Sarah and Nancy devoted minimal amount of time and discourse to orienting students to the activity. In both cases, there were instances – presented in chapter 4 – where this resulted in the need for interactions with students devoted to clearing up confusion related to the goal of the activity and the significance of the problem being investigated. Further, an example from Nancy’s period 4 class was offered to indicate the effect that such a deficient framing component can have on students’ ability to navigate the problem space. One of her students – Cole – noted that without a referent for judging the efficacy of the proposals in the Zn-S reaction (such as Hannah provided her students), it was difficult to know whether the initial proposal was close or far off and therefore where to begin in formulating alternative proposals.

2. Teachers’ nuclear initiating moves defined how ‘dead end’ instances were treated and how alternative ideas were explored.

In chapter 4, an example (from her period 3 class) of the kind of utterance which Sandy used to initiate the conversation following a dead end instance was presented:

75. Sandy: So what must be true about why – why do you think it didn’t work? Nuc. I Req. I / P

Later in this chapter, an example of the kind of utterance which Nancy employed at a similar point in the activity (in her period 3 class) was also offered:
210. Nancy: All right. So I’m saying to you: “I’ve seen that better and we can do – we can get a little bit more out of that.” So I’m not so sure that we have these points to mass values offered by students as part of equal-mass solution right. So my question to you now is, How might you change it and why?

Nuc. I Req. I / P

Each utterance set the tone for the interactions related to how to proceed from the given ‘dead end’ instance and sent a message to students as to what the content of those interactions should be. In Sandy’s case, the focus in her turn on “why . . . it didn’t work” treated the dead end as a locus of learning and suggested a practice of mistake analysis. The idea of mistake analysis is part of van Oers’s (1984) framework for promoting sophisticated trial-and-error, as can be found in his description of The Solution of Problems in Co-operative Activity:

Characteristic for this level of problem-solving is the fact that the subject’s attention is focused primarily on the course of actions and on their bases and not exclusively on the results of actions. Subjects are constantly looking for mistakes in the verbal propositions of other participants, considering the coherence of their joint plan. (p. 247)

Sandy’s utterance steered her students towards engaging in such a mistake analysis, and this process became encapsulated in the Explaining the Dead End segments which were unique to her lessons. Having their efforts directed towards tracing the line of reasoning in order to find the flaw in the logic of their initial proposal meant that Sandy’s students had the problem space constrained in a constructive way by allowing them to eliminate alternatives that might suffer from a similar flaw. Nancy’s students were pointed in a different direction by her turn, with the emphasis on “How might you change it . . .” suggesting the goal of simply trying to come up with alternative solutions without using a rational analysis of the failed proposal to guide the generation of reasonable possibilities. This difference between Sandy’s and Nancy’s key nuclear initiating moves speaks to another aspect of the way the interweaving of the expansion and openness commitments might be conceptualized in the MSP lessons to most effectively support
progressive discourse, a consideration which will be addressed in the *Implications* section.

3. The interactions related to discourse moves supporting the openness commitment were focused more on students’ ideas rather than on their reasoning.

The following passage (not presented previously) was pulled from part of a larger monologue conducted by Marty in his period 4 class as he prepared students to conduct the empirical test to determine if their predicted trends for atomic radii were correct:

219. Marty: . . . So I will give you this paper. You have to: Look up your elements; copy down their atomic radius – which is in the middle over here; put them in order – you don’t have to have your cards to do this, just look at your elements that you wrote down; check and make sure that is the correct trend. If it’s the correct trend, we’re going to assume that your reason is correct. If you don’t have the correct trend, I would like you to come up with a reason why the ‘true trend’ exists.

The content of that passage – particularly the next-to-last statement – should be compared to this utterance from Nancy’s period 3 class which was presented in the *Interactions* sub-section of her case study in chapter 4:

257. Nancy: Okay, I’m not *saying* you’re wrong, I’m *giving you a reason*, right? Okay, so, I’m not necessarily saying that your *idea* is wrong, I’m saying your reasoning [pause] doesn’t hold. Okay?

In Marty’s passage, he makes the statement, “If it’s the correct trend, we’re going to assume that your reason is correct,” which treats the idea and reasoning as being the same. By comparison, in the case of Nancy’s utterance, she distinguishes between the *idea* and the *reasoning* and treats them as entities to be considered separately.

Recognizing the importance of the distinction found in Nancy’s utterance, the researcher was lead to create separate code categories for support // modify // refute *idea / proposal* and support // refute *reasoning*. As was noted in the quantitative data presented at the end of chapter 4, there were 109 instances of support // modify // refute *idea / proposal* (3.7% of coded data) as
compared to 48 instances of support // refute reasoning (1.6% of coded data. Even if the [10] cases of modify idea / proposal are removed from the preceding figures to give the same number of code categories in each set being compared, there were still over twice as many instances of evaluations of an idea / proposal than there were of evaluations of reasoning. This propensity to more readily evaluate the idea / proposal than the reasoning is understandable given that it can be less intellectually demanding; however, it may not be the most appropriate way to develop the kind of scientific thinking being promoted in the science education literature (e.g. Duschl, 2008; Osborne, Erduran, & Simon, 2004). Moreover, given that teachers conducted 41 of the 157 instances (26% of the cases) of support // modify // refute idea and support // refute reasoning, any utterance which echoes this focus on ideas over reasoning will further reify this tendency in students as an acceptable way to conduct a critical analysis. (An example of this was presented in the Interactions sub-section of Nancy’s case study related to the way she repeated a criticism of the ‘13.08 gram’ proposal itself, based on the fact that it represented “a lot of sulfur.”)

4. Teachers participation in interactions related to the empirical testability commitment defined the students’ ownership of the process of analyzing the test results.

Discussing the relative merits of Ernst von Glasersfeld’s radical constructivism (versus James’s radical empiricism) as a pedagogical framework, Phillips (2002) points to a conundrum which those who might employ such a framework eventually face:

. . . should a constructivist teacher stand by and allow a student to construct an incorrect version (incorrect by current disciplinary standards) of, for example, Newton’s law of gravitation? As one well-known contemporary essay in science education posed the issue, “when do I tell them the right answer?” (Wadsworth, 1997). (p. 128)

The participating teachers who conducted the Zn-S-reaction lesson were confronted by a similar challenge: What do you do when the results of the testing support a solution to the
problem other than the one which would be predicted by the normative scientific explanation?
The interactions related to the way in which two of the teachers – Sarah and Hannah – responded
to this challenge were documented in chapter 4. In both cases, these teachers went beyond acting
as neutral recorders of the testing data and became active participants in the process of analyzing
and interpreting this data. (In fact, the quantitative data presented at the end of chapter 4 showed
that 15 of the 151 instances of give a prediction // observation // analysis were conducted by
teachers.) More significantly, in both cases the teachers used what could be labeled as their
‗powers of suggestion‘ to insure that the test results associated with the normative scientific
solution to the problem were given the most favorable interpretation. This finding connects to
the results of research by Howe et al. (2000) discussed in chapter 2. While determining that a
teacher‘s participation in the activity of hypothesis formation could offer a benefit in the form of
the scaffolding that it provided, these authors cautioned that this contribution could be under-
mined if a teacher used her/his position of authority to impose her/his ideas on students. This
research has indicated the way this kind of deleterious effect might be extended to other
components of science classroom activity.

Implications

From its beginning this study had an underlying objective of translating the research
findings into a set of principles which would allow teachers to structure an MSP lesson so as to
most effectively support the principles of progressive discourse. In this section the results of that
translation of theory into practice will be offered in the form of a set of pedagogical implications
related to conducting an MSP lesson in a way which can maximize the likelihood that the
students’ knowledge after the lesson will be better than it was before.

1. Adopting the proper metaphor and vision for conducting a lesson of this nature.
Describing her recognition of the need to reconstruct the metaphor for her own role as teacher, van Zee (2000) had this to say about her proper place in the inquiry discussions occurring in her class:

I no longer view myself as a facilitator of discussions, but rather as an organizer of learning events in which my students share the authority to make decisions about what to say and do next. I practice ‘quietness’ by waiting before and after student talk (wait time), listening to the details of other people’s thinking without interrupting them (attentive silence) and withholding my own opinions and understandings while assisting others in expressing theirs (reticence). (p. 115)

In interview 3, Sarah identified an aspect of the role she assumed in the videotaped lessons which may have hindered the goal of achieving progressive discourse (from A.1):

Sarah: I felt . . . I felt good about it [the way she conducted the sample lessons] on the one hand, and on the other hand I [pause] . . . still [pause] . . . struggled with, like, telling them whether or not it was right or wrong. Like I actually – when I went back and started watching some of the tapes – I realized that instead of letting the students of the class evaluate each other’s, um, statements about what we already knew about the reaction, I ended up doing that, sometimes, for them and I was like, ‘Oh my gosh, that’s not what I’m supposed to do.’

Sarah’s comment speaks to the challenge of moving away from a ‘Teacher as Evaluator’ metaphor – which is so ingrained in the experience and practice of teachers – to some other metaphor which would allow students to assume this role – something van Zee seemed to be addressing in her reticence criteria. Likewise, the following exchange from interview 5 (A.1) with Nancy conveyed the insight she gained through her participation in this research related to van Zee’s attentive silence criteria:

Nancy: And, I think what I’ve found is that, um, I can allow them [the students] to lead the conversation more and it’s okay. Um, they’re more . . . The tendency is that if they have the right background and the right prior knowledge – whatever you want to say – you know, they’ll lead the conversation in the right direction at some point. So, I’m not so afraid to have it go off- . . . Like, a good . . . I did that other lesson with the eighth-graders, the next day and I did – I just let them go, I just . . . You know, I did the demo and I just let them talk and they ended up . . . We ended up until the next . . . actually, it was over a weekend, so it ended up [going] until the next time and, um, they just went ahead [with the conversation]
and they led it straight into air pressure. I mean, they did, they got it . . .

Related to this evidence was presented that four of the five participating teachers (everyone but Hannah) went into this lesson with a focus on exploring mainly the ‘correct’ solution and the most likely ‘incorrect’ (or misconception-based) solution. In other words, the data indicated that these four had adopted a discrepant event (Limon, 2001; Wright & Govindarajan, 1995) or binary solution pathway vision of how to structure the lesson. For example, Sandy explicitly noted that – out of three solutions proposed by her students in the period 7 lesson – she wanted them to pick the one corresponding to the most common misconception (equal mass of sulfur) to perform the first test upon and was concerned about what she would do if they didn’t make this choice. In Sarah’s lessons, she actually offered the equal-mass solution as a proposal herself in two of the classes where students did not generate it. Given the prevalence of the discrepant event teaching strategy in the science education literature, it will be important for teachers to move beyond this to adopt a more expansive vision of what ideas are explored during these MSP lessons so student notions such as ‘metals are more reactive’ do not get overlooked as fodder for meaningful classroom dialogue.

2. Providing the proper orienting basis for the activity.

The inherent complexity of the MSP lesson can be mitigated by framing the activity in a way that makes salient (1) the goal of the problem-solving work to be done and its value; (2) the set of actions which will be necessary to accomplish that goal and the relationship between them; (3) the tools necessary for achieving this goal; (4) a measure that will allow the participants to know when the goal has been achieved; and (5) the responsibilities of the participants in working towards the goal. These elements could be ascertained by a consideration of the Building Up the Problem segments of Marty’s and Hannah’s lessons and it was in their lessons that students
seemed to be the most clear about what they were to be doing. To this could be added the utility of connecting the activity to the broader ‘storyline’ of the course, a component of the orienting basis of Sandy’s lesson which helped to create the appropriate context.

The orienting basis, though, cannot be thought of only in terms of what the teacher does at the beginning of the lesson; teachers need to also provide the proper orientation to major shifts in the action of the lesson. In two examples presented in chapter 4 – one from Nancy’s class and one from Sarah’s class – students expressed confusion during the transition period between the proposal / evaluation of ideas and the testing of those ideas; this might have been avoided with proper framing of the testing segment – particularly its relationship to the previous segment. Also, teachers will need to be prepared to re-orient students to changes in the goals and sub-goals of these MSP lessons as circumstances dictate: One thing which made Sarah’s period 5B lesson unique is that she re-defined the goal of the activity partway through the period to make it better align with the ideas her students had proposed.

3. Employing a structure of idea exploration which effectively balances the expansion and openness commitments and promotes a sophisticated view of trial-and-error.

In the previous section, one of the points made was that the structure of activity utilized by Nancy, Sandy, and Sarah favored the openness commitment at the expense of the expansion commitment; conversely, the structure of activity employed by Hannah and Marty gave precedence to the expansion commitment over the openness commitment. The ideal would be a structure of activity which lends equal credence to both commitments and balances the desire to consider as many student proposals as possible with the need to critically evaluate all proposals. One could imagine relatively straightforward modifications of any of the enactments videotaped which could allow this equilibrium to be achieved, such as introducing a formal ‘vetting’ seg-
ment in between the Proposing Solutions and Testing Proposals segments in Hannah’s lessons.

Striking the kind of balance just described would promote in students a sophisticated view of trial-and-error in the science classroom (and perhaps in disciplinary science as well). Another way that the structure of activity could support this view would be to recognize ‘dead end’ moments as loci of learning by ensuring that students engage in a process of mistake analysis (as happened in Sandy’s lessons) following these instances instead of simply allowing them to proceed to their next ‘best guess’ (as happened in Nancy’s lessons). A related option is to have students engage in a reflective action such as in the Revising the Plan segments of Hannah’s lessons in which students were encouraged to take other student’s ideas and the results of empirical tests into account as they were given the opportunity to reformulate their proposals.

4. Utilizing a discourse model which fully taps the potential of progressive discourse and its associated commitments.

Support for the suggestion that teachers need to move away from the ‘teacher as evaluator’ metaphor (made in point 1 of this section) is the data from chapter 4 which showed that teachers conducted 26% of the support // modify // refute idea / proposal and support // refute reasoning moves (related to the openness commitment) and 10% of the give a prediction // observation // analysis of results moves (related to the empirical testability commitment). While it will be valuable for teachers to model such moves in the initial excursions into activities of the nature of the MSP lesson, it is imperative that teachers check their inclination to engage in such practices later on and turn them over to students. A good example of the impact of this approach can be found in Sarah’s period 5B lesson, where she refrained on making an evaluation of students’ different interpretations of what the term ‘ratio’ was referring to and, through doing so, allowed the two different proposals in this class to emerge spontaneously from the conversation.
Again, relatively small modifications in some of the videotaped enactments would have allowed this strategy to be realized. For instance, in Hannah’s period 3 class, after one group had just offered their proposal (of ‘12 grams’) and supported it, in part, by saying that “it’s not too little [an amount]” (line 36), Hannah follows-up the proposal made by the group presenting in the succeeding sequence (of ‘6.54 grams’) by asking, “What do you think about what they’re [referring to previous group] saying – more makes a bigger reaction?” (line 44). The interaction associated with this turn was not presented in chapter 4 because it was the only example of this particular move by Hannah from the 18 sequences found in the Sharing Out [Initial] Proposals segments in her three classes. It is likely that if Hannah had conducted this move on a regular basis, students would have eventually taken ownership of it and have gained a powerful tool for exercising the openness commitment.

In a similar manner, if instead of performing a re-utterance move in the final turn of each sequence in the Sharing Out segments of his classes (discussed previously), Marty had posed a request for evaluation similar to the one above that Hannah utilized, it is likely that students eventually would have begun to make their own comparisons to ideas already presented – a practice which O’Connor and Michaels (1996) noted is rare in American science classrooms. Not only would this have helped them in internalizing discourse processes supportive of the expansion and openness commitments, but it might have also made them cognizant of the contrasts between the ideas being offered that otherwise were overlooked.

Included in the discourse practices for which teachers should provide models / scaffolds for students would be those that recognize that ideas and reasons are separate entities, but that both need to be evaluated and that this evaluation should include an analysis of the relationship between a particular idea and its reason. This would help support some of the recent work to
promote more effective argumentation discourse in science classes (e.g. Nussbaum, Sinatra, & Poliquin, 2008; Sampson & Clark, 2009; von Aufschnaiter, et al., 2008).

Limitations of This Study

One of the main limitations of this study was the set of contexts in which the data for it was collected. All of the teachers worked in schools which were (a) almost entirely populated by Caucasian students (more than 99% of the student body), (b) found in residential or rural communities, and (c) smaller in size (with Sarah’s school being the largest, being rated as a AAA school in Pennsylvania’s system). This leaves open the question of whether the MSP lesson structure could be enacted as readily and whether those enactments would look the same in schools with substantial populations of non-Caucasian students or in schools located in urban settings. A related issue is the fact that these lessons were all conducted in classes consisting of more academically-oriented students in the college preparatory track in their schools’ curriculum. Further, with the exception of Nancy’s period 6 lesson, all of these instantiations took place in classes of higher-performing students.

A second limitation of this study was that teachers did not receive a true professional development experience related to Bereiter’s notion of progressive discourse and the manner in which the ideas underlying it might be translated into these MSP enactments. While this offered a more naturalistic perspective on how the teachers thought about these ideas and how those thoughts became actualized in the structure of activity and the types of interactions which occurred in their lessons, it probably reduced the extent to which the teachers were able or willing to incorporate practices beyond their normal repertoire of pedagogical strategies. Several studies have discussed the influence such professional development experiences can have on teachers’ ability to implement reform-based curricula (e.g. Donnelly, 2005; Lederman et al.)
2003; Ryder & Leach, 2008).

A third limitation was methodological. Given that one of the objectives was to look at the way ideas were explored during these MSP enactments, the discussions that took place during the Generating Solutions segments of each lesson represented valuable pieces of data. Those discussions largely occurred in small-group formats, and the microphone on the video camera only captured some restricted portion of these conversations; thus, some worthwhile information was lost. In more recent work within this research program, attempts have been made to overcome this limitation by strategically placing individual audio recorders at various places around the classroom during the Generating Solutions task segments.

The final limitation is theoretical. The framework presented in the Introduction lead to a focus on specific interactions and specific features of the structure of activity within the videotaped lessons. As was described in the Research Methods, that framework provided a lens through which the discourse function codes were conceptualized. With the influence that the theoretical framework had on both the researcher’s way of ‘seeing’ the events of the lesson and the methods used to analyze those events, it is likely that aspects of the interactions and structure of activity following outside the purview of that framework were given insufficient attention.

Future Directions

This study set out to characterize the interactions which occurred as the five participating teachers enacted their visions of the MSP lesson and to examine how those interactions related to the structure of activity and exploration of ideas within those enactments. The key insights obtained from that work have been presented in the preceding pages. While the presentation of findings could be viewed as closing the book on this particular line of work, this researcher prefers instead to look upon it as providing the opening chapter in a larger research program.
This last section will describe the future avenues of inquiry in this research program, including some work that has already been done.

One of the main goals for future work will be to find ways to shift the onus of conducting discourse moves supportive of the principles of progressive discourse from the teacher onto the students. A means for helping to promote this shift has already been devised: In the vein of work done by Herrenkohl and Guerra (1998), a set of questions have been built off the progressive discourse commitments which audience members are asked to attend to while other class members are speaking. That set of questions is (1) Does the speaker’s idea make sense to me and do I understand where that idea comes from? (Mutual Understanding); (2) Does the speaker’s idea make me think of a related idea or give me a different idea? (Expansion); (3) Are there things that I know which might support the speaker’s idea or make me question that idea? (Openness); and (4) How can I figure out whether the speaker’s idea – or others that are on the table – is a good one (or the best one) for solving the problem at hand? (Empirical Testability). This Critical Listener model has already been employed in later iterations of the lessons video-taped for this study and has produced interesting transformations in the kinds of interactions which take place and in the way ideas are explored.

A second avenue for future work is to return to the research direction initially intended for this dissertation study: an examination of the relationship between certain psychological factors [e.g. need for closure (Kruglanski & Webster, 1996) and tolerance for ambiguity (Furnham & Ribchester, 1995)] and the way that students participate in the MSP lesson structure. Students are used to neatly packaged presentations of content which flow in a simple linear fashion from beginning to end; in many cases, the MSP lesson will have features in direct opposition to this traditional lesson structure. For at least one student (Troy from Marty’s period
4 class) interviewed for the current study, the alternative offered by the MSP was less appealing than the traditional approach:

That was a good learning experience I would say, probably. Um, I learn better by probably listening, and like writing down the stuff, so I can go back and look over it and study. And some people learn more by trying it out and, like, seeing it, so . . . for me, I’d rather him teach me – like, tell me how the trend is. (Section B.1)

Is Troy’s preference for the more traditional approach a function of being inculcated into this way of doing things through years of formal schooling or is it a function of his proclivity for maximal clarity (and minimal ambiguity) in his learning? Examining whether a relationship exists between the appropriate psychological factors and students’ form and level of participation in MSP lessons could help answer such a question.

A final focus for future work related to this program will be around professional development experiences designed to provide a dialogue framework through which teachers can better facilitate classroom interactions supportive of progressive discourse. The dialogue framework employed in those experiences will represent a synthesis of the work of Bereiter (1994), Kress et al. (1996), Leach and Scott (2002), and Halliday and Martin (1993). Further, it will use the digital dialogue game software (see www.interloc.org/index.htm for an overview) employed by Ravenscroft (2000, 2007) in his research as a platform through which teachers can actively appropriate the framework in an authentic context. The questions of interest in this area of the future work will be (1) How does participation in such a professional development experience influence the way teachers ‘hear’ the discourse in their classrooms? and (2) How do they transform the dialogue framework into changes in their classroom practice? Answering those questions will help provide the information needed to translate the theoretical insights culled from this dissertation study into practical applications which can help in-service teachers to model and guide genuine ‘science talk’ in their classrooms.
Appendix A: Informed Consent Form for Teachers

INFORMED CONSENT FORM FOR SOCIAL SCIENCE RESEARCH
The Pennsylvania State University

Title of Project: Developing a Practice-Based Theory of Science Pedagogy

Principal Investigator: Scott McDonald, Assistant Professor
146 Chambers Building
University Park, PA 16802
(814) 865-2190; smcdonald@psu.edu

1. **Purpose of the Study:** The project is an effort to develop a theory of science pedagogy grounded in practice. This will be accomplished through the collection of video data in a variety of contexts for use as both professional development and research purposes. Participants will be videotaped teaching representative lesson and review their teaching with a researcher in a stimulated recall format in an effort to draw out theoretical constructs that make up elements of science pedagogy.

2. **Procedures to be followed:** Participating teachers will fill out either a questionnaire concerning beliefs about practice (the Teachers’ Pedagogical Philosophy Instrument, TPPI) or concerning beliefs about knowledge (the Teachers’ Epistemological Beliefs Instrument, TEBI) in advance of the videotaped lesson. A pre-interview will also be conducted prior to the videotaped lesson to discuss expectations about the outcome(s) of the lesson. Finally, a post-interview will be conducted which will largely focus on the enactment of the lesson (in a stimulated recall format).

3. **Discomforts and Risks:** Since this research is simply designed to gather practicing teachers’ insights into best practices, there are no risks in participating in this research beyond those experienced in everyday life.

4. **Benefits:** This experience will provide you with the opportunity for reflective discussion concerning the challenging practice of science teaching and will give you access to a research group focused on supporting the development of best practices. Any insights obtained through this research will be shared with participants.

5. **Duration:** The questionnaire and pre-interview will require about 1 hour of time total. The videotaping will most likely occur during a single period. The post-interview is likely to take half an hour to an hour of time.

6. **Statement of Confidentiality:** Only members of the research group will know your identity. The data will be stored and secured at 146 Chambers Building in password-protected files. The following may review and copy records related to this research: The Office of Human Research Protections in the U.S. Department of Health and Human Services, Penn State University’s Social Science Institutional Review Board, and Penn State University’s Office for Research Protections. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared. Specifically, this means that while direct quotes from participants may be shared in write-ups, all identifying information including your name, the name of the school, or the names of any students, will be excluded. You will be identified only by a generic title (e.g. Physics teacher) in any references to you in write-ups from this work. If participants speak about
the contents of the group outside the group, it is expected that they will not reveal to other people what individual participants said.

7. **Right to Ask Questions:** You can ask questions about this research. Contact Scott McDonald at 865-2190 with questions. You can also call this number if you have concerns about this research, or if you feel that you have been harmed by this study. If you have questions about your rights as a research participant, or you have concerns or general questions about the research, contact Penn State University’s Office for Research Protections at (814) 865-1775.

8. **Compensation:** There will be no direct financial compensation for participation in this group.

9. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

All recordings (both audio and video) will be stored digitally on the PI’s computer and originals will be stored in the PI’s office at PSU. Only the PI and members of the group will have access to these recordings.

**Please initial to indicate your choice(s):**

_____ I give permission for my video recordings to be archived for use in future research projects in the area of science pedagogy.

_____ I do not give permission for my video recordings to be archived for future research projects. I understand the tapes will be destroyed on September 1st, 2016.

_____ I give permission for my video recordings to be archived for use educational and training purposes.

_____ I do not give permission for my video recordings to be archived for educational and training purposes. I understand the tapes will be destroyed on September 1st, 2016.

You must be 18 years of age or older, to take part in this research study. If you agree to take part in this research study and agree to the provisions outlined above, please sign your name and indicate the date below.

You will be given a copy of this signed and dated consent for your records.

______________________________________________________________________________  ____________
Participant Signature                                      Date

______________________________________________________________________________  ____________
Person Obtaining Consent                                      Date
Appendix B: Informed Consent Form for Students

INFORMED CONSENT FORM FOR SOCIAL SCIENCE RESEARCH
The Pennsylvania State University

(Format for Student in Participant Teacher’s Classroom)

Title of Project: Developing a Practice-Based Theory of Science Pedagogy

Principal Investigator: Scott McDonald, Assistant Professor
146 Chambers Building
University Park, PA 16802
(814) 865-2190; smcdonald@psu.edu

1. Purpose of the Study: The project is an effort to understand and improve science teaching in high schools.

2. Procedures to be followed: A lesson in your classroom will be videotaped to record the events of the lesson. It is likely that you will be on the videotape as part of your normal participation in class. It is also likely that you will be audiotaped during a group discussion to capture the conversation that occurs in your group. Finally, it is possible that you will be interviewed following the lesson. The interviews are designed to find out how you learn best in science classes and how you felt about the videotaped lesson. The purpose of all of this is to help a research group understand and improve the kind of teaching that takes place in science classrooms such as the one in which you are a member.

3. Discomforts and Risks: The ‘tests’ are short (either one can be completed in 20 minutes or less). The interviews are simply a chance for you to discuss your classroom experiences with the researcher. As a result, there are no risks in participating in this research beyond those experienced in everyday life.

4. Benefits: To help the researcher and your teacher provide the best science learning experience possible.

5. Duration: As noted above, the test will take about 20 minutes. If you are selected and agree to be interviewed, you will be interviewed twice and it is expected that each interview will last about 20 minutes. The videotaped lesson is expected to occur during a single class period.

6. Statement of Confidentiality: Only members of the research group will know your identity. The videotape will be stored and secured at Pennsylvania State University 146 Chambers Building in password-protected files. The following may review and copy records related to this research: The Office of Human Research Protections in the U.S. Department of Health and Human Services, Penn State University’s Social Science Institutional Review Board, and Penn State University’s Office for Research Protections. In the event of a publication or presentation resulting from the research, no personally identifiable information will be used. Specifically, this means that while direct quotes may be shared, all identifying information including your name, the name of the school will be excluded. You will be identified only by a pseudonym in any references to you in write-ups from this work.
7. **Right to Ask Questions:** You can ask questions about this research. Contact Scott McDonald at 865-2190 with questions. You can also call this number if you have concerns about this research, or if you feel that you have been harmed by this study. If you have questions about your rights as a research participant, or you have concerns or general questions about the research, contact Penn State University’s Office for Research Protections at (814) 865-1775.

8. **Compensation:** None.

9. **Voluntary Participation:** Your decision to be in this research is voluntary. If asked to be a participant in the interviewing process, you have the right to refuse. You can stop at any time. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

All recordings (both audio and video) will be stored digitally on the PI’s computer and originals will be stored in the PI’s office at PSU. Only the PI and members of the research group will have access to these recordings.

**Student please initial to indicate your choice(s):**

_____ I give permission for my recordings (audio and video) to be archived for use in future research projects in the area of science pedagogy.

_____ I do not give permission for my recordings (audio and video) to be archived for future research projects. I understand the tapes will be destroyed on September 1st, 2016.

_____ I give permission for my recordings (audio and video) to be archived for educational and training purposes.

_____ I do not give permission for my recordings (audio and video) to be archived for educational and training purposes. I understand the tapes will be destroyed on September 1st, 2016.

If you agree to take part in this research study and agree to the provisions outlined above, please sign your name and indicate the date below. Regardless of whether you are 18 years of age or older both you and a parent or guardian must sign.

You will be given a copy of this signed and dated consent for your records.

______________________________________________  ________________
Student Signature            Date

**Parent / Guardian please initial to indicate your choice(s):**

_____ I give permission for recordings (audio and video) of my child to be archived for use in future research projects in the area of science pedagogy.

_____ I do not give permission for recordings (audio and video) of my child to be archived for future research projects. I understand the tapes will be destroyed on September 1st, 2016.
_____ I give permission for recordings (audio and video) of my child to be archived for use educational and training purposes.

_____ I do not give permission for recordings (audio and video) of my child to be archived for educational and training purposes. I understand the tapes will be destroyed on September 1st, 2016.

______________________________________________    __________________
Parent / Guardian Signature                      Date

______________________________________________    __________________
Person Obtaining Consent
Appendix C: The Dead End Information Packet

Why a Classroom ‘Dead End’ Isn’t Always the Wrong Way to Go

“Liberating dark data takes this ethos one step further. It also makes many scientists deeply uncomfortable, because it calls for them to reveal their “failures.” But in this data-intensive age, those apparent dead ends could be more important than the breakthroughs. After all, some of today’s most compelling research efforts aren’t one-off studies that eke out statistically significant results, they’re meta-studies – studies of studies – that crunch data from dozens of sources, producing results that are much more likely to be true. What’s more, your dead end may be another scientist’s missing link, the elusive chunk of data they needed.”

--From the article Freeing the Dark Data of Failed Scientific Experiments by Thomas Goetz in the October 2007 issue of Wired magazine

Introduction

How many times over the course of your [science] teaching career have you felt like your students just weren’t getting it – they just weren’t understanding the ideas that you were so logically and eloquently presenting to them? It is likely that the source of the problem was not in what you were saying, but in what your students were not saying. Over the past two decades or so, research in science education has achieved [at least] one overarching and consensus conclusion regarding what constitutes effective science teaching: In order to truly understand science, students must be given the opportunity to talk science.

This information packet is designed to familiarize the reader with a teaching strategy – formally being called the dead end activity structure – which has the explicit goal of helping students truly understand science by making them more active participants in the process of talking science. One might be inclined to say that students do talk science all of the time in science classes. However, if you listen very carefully to the conversations that are occurring in many science classes, what you find is that students are really just saying science words. It has been clearly established that most classroom ‘conversations’ fit a pattern called IRE/F for
initiation, response, and evaluation / feedback. In this pattern, the teacher initiates the ‘conversation’ by asking a question – usually one with a single clear and often straightforward answer, a student responds by offering the science word or phrase that provides that answer, and the teacher then evaluates that answer (as right or wrong) or provides feedback (concerning the logic of the answer). While that pattern certainly has some value in terms of checking students for factual understanding, it does not necessarily help them truly learn science.

One might be puzzled as to why the IRE pattern does not necessarily insure that students learn the science. After all, if a student can answer the question, doesn’t that indicate comprehension? The problem is that many science teachers forget science is a language onto itself. For a large percentage of our students, it is a foreign language. While that last sentence probably invoked a cynical laugh in a few readers, give it some careful consideration for a moment. Think of it as a metaphor: Science as a foreign language. Is it a valid metaphor? Well, consider some of the words of science: homozygous, electronegativity, and kinematics. Are those any more familiar to our students than words like sacerdote, gazpacho, and juventud? And, even those words with which students are familiar – such as heat, force, and torque – often having meanings in science class which are far different than their meanings in everyday life.

Assuming you are convinced that the science-as-a-foreign-language metaphor is valid, what are the implications of this? Consider for a moment if the following imaginary dialogue was the only kind of talking that occurred in a foreign-language class:

T: What is the Spanish word for ‘cat’?
S: Gato
T: That’s correct

While students in the class would be very good at vocabulary quizzes, it is very likely that they
wouldn’t understand the language. In order to truly understand the language, students need to be given the opportunity to chance to put the words into new sentences, to try out their meaning in new contexts, to connect them together with other words to create cohesive thoughts in this foreign language.

It is really no different for our students in science. Each term that we want them to know is like a word from a foreign language, either by virtue of it being a word they have not seen before or a familiar word used in an unfamiliar [scientific] way. We cannot expect students to really learn these words by simply repeating them to us or by responding to what are effectively ‘fill-in-the-blank’ questions that many teachers use to check understanding. We can only expect them to genuinely learn these words by engaging in real dialogue around them, exploring the boundaries and extensions of their use, applying them in new contexts to ground their understanding. As teachers, then, our job becomes creating the opportunities for such legitimate scientific dialogues – talking science as linguist and science educator Jay Lemke called it – and our job becomes helping guide their use of the terms within that dialogue, much as a parent guides a child’s use of her/his first words.

Of course, for most teachers, the kind of practice just described is as foreign to their training and experiences as scientific terms are to their students. And, just as we cannot expect our students to successfully engage in conversations with those terms sans our guidance, teachers cannot be expected to provide such guidance sans some support. The purpose of the remainder of this hand-out is to provide that support by offering a set of practices – and the principles that underlie them – that can allow students to engage in meaningful scientific dialogue – to truly have the chance to talk science.
Exploratory Talk

Following a large-scale research project that studied how collaborative activity occurred in primary schools in England, Mercer and his co-workers identified and described three styles of dialogue (N. Mercer, 1996):

(1) The first way of talking is *disputational talk*, which is characterized by disagreement and individualized decision making. There are few attempts to pool resources, or to offer constructive criticism of suggestions. Disputational talk also has some characteristic discourse features, notably short exchanges consisting of assertions and counter-assertions.

(2) Next there is *cumulative talk*, in which speakers build positively but uncritically on what the other has said. Partners use talk to construct a “common knowledge” by accumulation. Cumulative talk is characterized by repetitions, confirmations and elaborations.

(3) *Exploratory talk* occurs when partners engage critically but constructively with each other’s ideas. Statements and suggestions are offered for joint consideration. These may be challenged and counterchallenged, but challenges are justified and alternative hypotheses are offered. Compared with the other two types, in exploratory talk *knowledge is made more publicly accountable and reasoning is more visible in the talk*. Progress then emerges from the eventual joint agreement reached.

Mercer and his co-workers have shown that the third style – exploratory talk – can both enhance students’ reasoning abilities and improve their understanding of science content (N. Mercer, Dawes, L., Wegerif, R., & Samsa, C., 2004). Although this style and the related findings were based on *student-student* interactions occurring in small groups, one could easily imagine how the same type of dialogue could take place in a whole-class situation, with the teacher facilitating the discussion. As facilitator, the teacher could make sure that the goal of critical analysis of ideas eventually ending in joint agreement is achieved.

Of course, for effective exploratory talk to take place, the ‘mood’ has to be ‘right’.
Mercer et al. addressed this fact when they indicated that a number of ‘ground rules’ must be in operation for such talk to have its intended outcomes. Based on the findings from their study of numerous classrooms, Mercer and his research team produced the following list of ground rules:

1. all relevant information is shared;
2. the group seeks to reach agreement;
3. the group takes responsibility for decisions;
4. reasons are expected;
5. challenges are acceptable;
6. alternatives are discussed before a decision is taken; and
7. all in the group are encouraged to speak by other group members.

The ‘Dead End’ as a Structure for Building Exploratory Talk

While Mercer’s ideas may be useful for supporting our efforts to help students talk science more effectively, good conversations do not happen in a vacuum – they need a context, a setting. The dead end activity structure is being proposed as one way to provide that context, that setting. If you go back to the quote from the Wired magazine article, you get a sense of what a dead end in science represents. Its meaning is rather intuitive because of its meaning in our everyday world: It is a pathway (road) that leads us in the wrong direction, which causes us to run into the proverbial ‘brick wall’. What that quote also indicates, though, is that – in science at least – we can come away from the experience of having followed that pathway more knowledgeable than when we started down it. That is because of the notion that we can learn from our mistakes.

The ICISS (Invisible College of Inquiry in the Secondary Science) research team at Penn State envisioned dead end ‘episodes’ playing out in science classrooms in such a way as to
reflect the dead ends that occur in science. At their essence, dead end episodes would take place when a teacher would pose a problem for the class to solve. The students in the class would present solutions and each solution would be explored in turn. Inevitably, one (or more) of the solutions would cause the problem-solving effort to run into a brick wall. The students – with some guidance from the teacher – would have to find their way out of this wrong turn and back towards a more tenable solution. Hopefully, during the course of this journey – down both the wrong and right pathways, students will not only come to understand the concept underlying the solution better, but also how to reason more effectively in general.

Hopefully, the [brief] description just given makes it clear that a dead end episode offers the perfect context in which a science class could engage in exploratory talk. By the same token, appropriate use of exploratory talk could be effectively enhanced by its application to working through the dead end episode. The synergy between the two can be greatly improved, though, if teachers who enact the dead end have a more complete picture of how it might play out . . .

Components of the Dead End

Through the examination of several lessons that the ICISS team considered to be representative of the dead end ‘ideal’, several key components of the dead end were identified:

1. Posing the problem – The teacher clearly explains what the problem is and what the boundaries are for possible solutions to the problem.
2. Offering a solution(s) – Students will propose possible ways to solve the problem; the teacher should insure that the solution is explained as clearly as possible to the class.
3. Elaborating a solution – Details are added to the initial explanation provided for a particular solution.
4. Supporting a solution – Ideas are offered to show why the solution makes sense.
5. Refuting a solution -- Ideas are offered to show why the solution doesn't make sense.

6. Modifying a solution – The original solution proposed is recast in some way, either to be able to respond to a refutation or to counter empirical evidence against it.

7. Testing a solution – Some empirical evidence is gathered in an attempt to determine whether the solution is valid or not.

8. Analyzing a test – The evidence from an empirical test is interpreted to determine whether it supports or refutes a solution.

9. Hunting for a source of error – It is clear that a solution is untenable, but it is not clear where the error in the logic is so the participants search to find that error.

10. Identifying a flaw in solution pathway – Once a test has shown a pathway is untenable, it is necessary to find the logical flaw that may help in generating alternative solutions.

11. Closing a solution pathway – A decision is made that the solution is not viable and alternative solutions must be explored.

12. Formalizing an acceptable solution(s) – Once enough evidence has been accumulated and an appropriate solution has been agreed upon, that solution is formally presented in a clear and concise form.

Adding a Few Caveats

It is important for the reader to understand several things about the information presented in the previous section:

1. The components represent a list of possible events during a dead end episode; not all of these events will occur in every episode.

2. The list of components does not represent a sequence of steps to be followed. Like
any genuine scientific investigation there will be starts and stops and detours and, hopefully in the end, arrival at the desired destination.

3. The most effective enactment of the dead end – in terms of helping students to talk and learn science – is one in which the principles of exploratory talk are infused in the movement through the episode.

4. The formalizing component is very important to make explicit to students what has and has not worked as they journeyed through this process – to make the main points unambiguous and obvious.

Contributing to a Higher Purpose

To bring this discussion to a close, it seems valuable to reflect on a statement made earlier: “. . . in science at least – we can come away from the experience of having followed that [dead end] pathway more knowledgeable than when we started down it.” This point resonates with a set of ideas proposed by Carl Bereiter (1994). At the heart of his set of ideas is the notion that we are wrong to think that the goal of science is to discover indisputable facts; instead, it is to continuously progress in our understanding of the world around us: “It is not necessary to believe that science is approaching some objective truth, but it is necessary to believe that today’s knowledge is better than yesterday’s. Otherwise, there seems to be no point to science.” (p. 4) Bereiter captures this idea as the notion of science as progressive discourse.

For this goal of science to be achieved, Bereiter indicates that there are four commitments to which the members of the scientific community must adhere. They are (1) a commitment to work toward a common understanding satisfactory to all (Mutual understanding commitment); 2. a commitment to frame questions and propositions in ways that allow evidence to be brought to bear on them (Empirical testability commitment); 3. a commitment to expand the body of
collectively valid propositions (Expansion commitment); and 4. a commitment to allow any belief to be subjected to criticism if it will advance the discourse (Openness commitment).

If we want our students to really understand science – both its ideas (concepts, theories, equations, etc.) and its means of generating those ideas – then it makes a lot of sense that we should have our students participate in the same kind of progressive discourse in which scientists engage. Bereiter indicates that this has been a missing element in the way that science has traditionally been taught: “Hands-on school science has emphasized discovery. What has been missing . . . is the discourse into which experimental findings need to be brought and critically analyzed if they are to contribute to progressive understanding” (p. 8).

Having students engage in this progressive discourse will likely pose some challenges: The teacher will have to properly model and guide the students through the process of maintaining the four commitments which make progressive discourse possible. Mercer’s exploratory talk presents a framework for constructing the kinds of classroom conversations that can support this effort. The dead end structure offers a forum in which those conversations can take place around a meaningful pursuit – solving a problem. Put together, the idea of science [learning] as progressive discourse, exploratory talk as a means of partaking in this discourse, and the dead end as the scene in which this dialogue takes place, can be a powerful tool in the repertoire of a teacher to help students better understand both the principles and practices of science.

References

## Appendix D: General Overview of Main Questions for Teacher Interviews

<table>
<thead>
<tr>
<th>Major Category</th>
<th>Key Point</th>
<th>Sample Question</th>
</tr>
</thead>
</table>
| **A. Beliefs / Views Concerning**   | **Best Practices / Epistemic Beliefs**         | 1. Perspective on inquiry  
If you were observing a science classroom, what kind of things would you see that would indicate to you that the class was engaged in an inquiry experience? |
| 1. Perspective on inquiry           | 2. Role of classroom discourse / student talk  | 2. Your principle shows you the new observation rubric and one element on it is, ‘Teacher engages students in meaningful dialogue.’ What do you think ‘meaningful dialogue’ would represent in your classroom? How would you feel about the presence of this element? |
| 2. Role of classroom discourse /    |                                               | 3. Consider the following passage from Millikan’s lab notebook in which he recorded the data gathered during his Oil Drop experiment: “I have discarded one uncertain and unduplicated observation, which gave a value of the charge on the drop some 30 percent lower than the final value of $e$.‖ There are also these notes, written next to various data entries: “very low something wrong; . . . this is almost exactly right; . . . possibly a double drop; . . . something the matter; . . . publish this beautiful result; . . . no something wrong with the thermometer.” Based on these notes, do you think Millikan was justified in presenting his conclusion concerning the charge of the $e$ as an experimentally-proven fact? (Matthews, 1994, pp. 124 - 125) |
| student talk                       |                                               | 4. The researcher presents a scenario in which an experiment to determine the relative masses of copper and iron produces highly erratic data. After school, the teacher determines that the erratic data was produced by the use of galvanized nails as opposed to ungalvanized nails that were used in previous years. If you were that teacher, how would you handle this situation the next day, given that the students have not yet completed the requisite calculations? |
| 3. Error in disciplinary science    |                                               |                                                                                                                                                  |
| 4. Error in science classrooms      |                                               |                                                                                                                                                  |
5. View of scientific knowledge

In a recent issue of *ChemMatters* magazine, a student wrote in and said, ‘My chemistry teacher told us that science never proves anything.’ (Becker, 2007) What does it mean to you to ‘prove’ something? Do you agree with that statement? Would you / have you said anything similar to this to your students?

---There is a 2nd part to this based on the rest of the student’s question.

### B. Planned Enactment of the MSP Lesson Structure

<table>
<thead>
<tr>
<th>Structure</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Student background</td>
<td>1. What content has preceded this lesson in your curriculum? What understanding of the concept central to this lesson do you expect your students to have?</td>
</tr>
<tr>
<td>2. Meaning / implementation of progressive discourse</td>
<td>2. What things in the description of progressive discourse you read resonated with the way you already thought about teaching science? What aspects of this idea seem new / unique to you and may limit the ways in which you are able to use this idea?</td>
</tr>
<tr>
<td>3. Concerns about enactment</td>
<td>3. What issues do you (the teacher) and I (the researcher) need to think about in order to make you comfortable presenting this lesson and conducting the kind of conversation with your students that matches the description you just gave (in response to 2.)?</td>
</tr>
<tr>
<td>4. Planning / expectations for MSP lesson</td>
<td>7. What is it about this lesson that you think made you choose it as a context in which the MSP structure might be used? What kinds of solutions do you expect students to come up with related to the problem that you are going to pose to them and which students will likely be active / inactive in proposing solutions?</td>
</tr>
<tr>
<td>5. Classroom conditions / culture necessary to conduct MSP / PD</td>
<td>8. What kind of things do you think a teacher needs to do / to have present in her/his classroom to be able to use the MSP structure / progressive discourse with students in order to help them learn science in the best way possible?</td>
</tr>
</tbody>
</table>

---Probes related to what norms / discourse practices already exist
| C. Actual Enactment of the MSP Lesson Structure | 1. Modifications between presentation of lesson in different classes | 1. What changes did you make (if any) in presenting this lesson to successive classes? What prompted you to make those changes and what kind of impact do you think they had? |
| | 2. Self-evaluation including modifications in future implementations of lesson | 2. How did you feel about this lesson and the way that it played out? Based on your sense of how the lesson went, what changes would you make if you were to do this again next year? |
| | 3. Keys / challenges for effective implementation of MSP structure | 3. What are the features of this kind of lesson that are central to its success or what practices does the class need to engage in for it to work? What were the challenges you faced as you tried to implement this lesson with your classes? |
| | 4. Critical junctures / surprise events or participants | 4. This involved the recounting of an event that the teacher / researcher saw as crucial to the unfolding of the lesson (or the use of video to review that event; see discussion following the table concerning this aspect of the interviews) and a discussion of the reasons that it evolved the way it did. Also, teachers would indicate events that surprised them or students who unexpectedly participated (based on previous involvement). |
| | 5. Value / limitation of this kind of lesson | 5. What is the value to student learning in taking the time to conduct a lesson like this which can be so time-intensive? What limitations might there be (institutional, local, etc.) related to teachers using this lesson structure on a regular basis? |
| | 6. Connections to future lessons / other contexts of applicability | 6. How will you build off of this lesson into other lessons / activities? What other lessons / classes are there in which you think this lesson structure might be useful? |
Appendix E: General Overview of the Core Issues and Questions for Student Interviews

<table>
<thead>
<tr>
<th>Core Issue</th>
<th>Interview Questions Posed [*]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The nature of scientific knowledge</strong></td>
<td>1. *Students were presented the same scenario from the ChemMatters article as the teachers were and then asked, ‘Do you agree with the teacher (in the article) that science doesn’t prove anything?’ [9 out of 20]</td>
</tr>
<tr>
<td></td>
<td>2. What is the purpose of science and how do scientists accomplish this purpose? [7 out of 20]</td>
</tr>
<tr>
<td></td>
<td>3. Do scientists make mistakes in their research work? If so, how do you think they know when they’ve made a mistake?</td>
</tr>
<tr>
<td><strong>The nature of classroom science knowledge</strong></td>
<td>1. <em>If you came back to school ten years from now and looked at your textbook, would it have all of the same information in it found there today? Why or why not?</em> [5 out of 20]</td>
</tr>
<tr>
<td></td>
<td>2. Do you make mistakes in your experimental work in this class? How do you know when you’ve made a mistake and how can you learn from those mistakes?</td>
</tr>
<tr>
<td><strong>Alignment between classroom science and disciplinary science</strong></td>
<td>1. Is the way that you’ve described science working [based on their answers to the questions related to the first core issue] the way that science is done in here?</td>
</tr>
<tr>
<td></td>
<td>2. <em>Are the experiments that you do in here similar to the experiments done by scientists?</em> [4 out of 20]</td>
</tr>
<tr>
<td><strong>Cultural norms of the classroom</strong></td>
<td>1. <em>Do you have freedom during the experiments you do to try out different ideas that you may have?</em> [7 out of 20]</td>
</tr>
<tr>
<td></td>
<td>2. <em>Was the kind of talking that occurred during this lesson similar to the kind of conversations that occur in most lessons?</em> [8 out of 20]</td>
</tr>
<tr>
<td></td>
<td>3. Did you see this lesson as being similar to or different from a typical lesson in this classroom overall?</td>
</tr>
</tbody>
</table>
| Recollection of proposed solutions and efficacy of each | 1. What was the original idea you had about solving the problem?  
2. Did you consider any other solutions to the problem and, if so, where did the ideas for those other solutions come from?  
3. What were some of the solutions that other students proposed?  
4. *How did you know which solution was the most effective?* [14 out of 20] |
| --- | --- |
| Conceptual understanding achieved | 1. Why did the solution your class ended up agreeing upon work best?  
2. Why did the other solution(s) not work as well? |
| Value of this lesson compared to other possible approaches | 1. The teacher could have come in and simply presented the problem to you and then worked you through the solution instead of asking the class to propose solutions. Was it valuable for the teacher to have done it the way that s/he did and, if so, why? |
| Concerns with misconceptions | 1. Some people have indicated a concern with this approach to teaching. This concern is that, with all of these different ideas out there, students may have a hard time remembering the correct solution and may, in fact, remember incorrect solutions. Do you think that this will be a problem for you? Why or why not? |

*Questions presented in regular font were asked of all of the student interviewees (core questions). Those presented in italicized font were only asked if time was available or if an interviewee’s response dictated this (auxiliary questions); the information in the brackets is the number of students out of the twenty interviewed who were asked each auxiliary question.*
Appendix F: StudioCode® Timelines with Task and Step Markers for Two Lessons

1. Sandy’s Period 3 Lesson

2. Nancy’s Period 3 Lesson
Appendix G: Solution Pathway Maps for the MSP Lessons

<table>
<thead>
<tr>
<th>Symbol</th>
<th>What It Represents</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Symbolizes a task segment that involves work which was done on building up the problem, or generating, proposing, evaluating, and revising solutions</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Indicates a task segment that involves the empirical testing of a solution proposal; a dashed version indicates a test whose validity was brought into question which may lead to a re-test</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Represents a task segment in which the results of a test were discussed and analyzed in terms of what they indicated about how tenable a particular solution was</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Depicts the task segment in which the ‘correct’ solution is identified and a discussion of why this solution was tenable (and, perhaps, why others were not) is undertaken to bring closure on the activity</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Symbolizes an idea that contributes to the development of a solution proposal but which is not the proposal itself</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Indicates a solution proposal offered by student; information about the proposal will be found in the text contained in the object</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Represents a solution proposal offered by a teacher; information about the proposal will be found in the text contained in the object</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Depicts a discussion of some length that either elaborates on a solution proposal or provides information in support of an idea</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Symbolizes a discussion of some length that criticizes a solution proposal or brings into question some aspect of its logic</td>
</tr>
<tr>
<td><img src="image" alt="Text" /></td>
<td>Indicates a dead end ➔ the point at which a proposal is determined to be untenable; a dashed version indicates some uncertainty about this. The text inside will explicate what kind of information indicated this.</td>
</tr>
</tbody>
</table>
Hannah's Period 1 Lesson
Solution Pathway Map, Pt. 1

1. MS1 in line 56
   2. Based on trying succession of masses
      2.1. Reg. for pred. in seq. 23&25

2. MS8 in line 48
   2. Justified based on periodic table in line 50
   2.1. Reg. for prediction in seq. 10&42

3. MS6 in line 45
   2. Justification is inaudible
   2.1. MS3 suggests in line 103 (seq. 38) and bases on MS6's logic
   2.2. Also connects to mole idea from previous unit (line 106)

4. 6.54 g.
   1. MS4 in line 33
   2. "So it's balanced"

5. 10 g.
   1. MS13 in line 40
   2. "Just guessing"

6. 3.21 g.
   1. MS3 in line 45
   2. Justification is inaudible

7. 3.27 g.
   1. MS11 in line 24
      (also MS5 and MS10)
   2. Based on gunpowder
      (Sulfur suffocating the reaction)

8. 6.54 g.
   1. Sequence 7 →
      MS3 proposes "3.37 g.", see also sequence 8
      where group members connect it to gun powder
   2. Sequence 11 →
      Back corner group
      (who proposes normative solution later) says "8 g." (MS8)

9. Building Up Problem
   1. Does Not go over the question about the reaction
   2. Used in model rockets
   3. Shows Video
   4. Hand-out with 2 hints
      (Pusiness and 15 g. 5 limit)
   5. Work in lab groups (see line 15)

10. Sequences 01:00-3:37
    1. Sequences 2-10 10:38-10:48
    2. Sequences 10:20-10:48

11. Generating Proposals
    & Justifications
    1. Sequence 7 →
       MS3 proposes "3.37 g.", see also sequence 8
       where group members connect it to gun powder
    2. Sequence 11 →
       Back corner group
       (who proposes normative solution later) says "8 g." (MS8)

12. Sequences 10:20-10:48
    1. MS13 in line 40
    2. "Just guessing"

13. Sequences 39-47
    1. Seq. 48
    2. Seq. 49-54

14. Cond. Test 1
    1. Seq. 50-54
    2. Seq. 55

15. Revise Plans 1
    1. Seq. 50-54

16. Revise Plans 2
    1. Seq. 55

17. Based on MS2/10's
    suggestion for more drastic change in sequences 48&52

continued
Hannah's Period 1 Lesson
Solution Pathway Map, Pt.2

1. Request for prediction in sequences 56, 57, 59, 61
2. See lines 174, 178, 179

1. Put best two proposals - 2 g & 3.21 g side by side
2. Lines 206, 208 & 209

1. No clear consensus about best result (see lines 231-207)
2. "5.15 g."
3. "No good"
4. "Nothing" See lines 250-263 for debate and Hannah's influence on this

1. Connects to MISB's solution (3.21 g.) in line 278
2. Also makes sure to address use of 1/10 mole of starting material (line 282); also, see sequence 80 related to this
3. Notebook question that she leaves them with (see sequence 91) focuses on the 'correct' solution
Hannah's Period 3 Lesson
Solution Pathway Map, Pt.2

1. Bums very impressively

1. Sample does not ignite

1. Flares up but doesn't really burn
   Sequences 48-61
   41:30-53:02

1. Ignites quickly and burns for several seconds

Testing Their Samples 2

Zinc Issue Revised

Analyzing Overall Results

Sequences 52-79
53:03-1:07:09

Formulating the Solution

Sequences 80-86
1:07:10-1:17:10

1. Seq. S2 is organizational
2. Seq. 63-66 devoted to using proposals around 3 grams to examine zinc year issue
3. Seq. 67-71 devoted to using proposals in 6-7 gram range to examine zinc year issue
4. Seq. 72-76 devoted to using proposals above 7 grams to examine zinc year issue
5. Sequence 76: “More is not better” conclusion: “some debate over validity of Hannah’s entries for 6.54 g samples
6. In 610, Hannah finishes guiding students to honing in on values around 3 grams as giving best results

1. Sequence 80 connects to FS16/17’s idea about periodic table masses; asks FS20 to re-explain in line 618; takes over for her in line 620 when she struggles.
2. Doesn’t really connect to unsuccessful proposals, although statement by FS17 in line 633 gives her the opportunity to do so (Hannah largely talks past this)
3. Gives them assignment to explain why 3.21 grams of sulfur was ideal amount
Hannah's Period 4 Lesson
Solution Pathway Map, Pt.2

1. Requires revisions in seq. 65-67
2. Proposed by MS1 & MS11
3. Sample does not ignite

Formalizing the Solution

1. Asks FS6 to re-explain MS5's idea, then expands on it herself (seq. 74)
2. Sequence 75 Addresses "more is better" misconception; this is questioned in a sense by MS9 in line 287 (although there is no uptake by Hannah)
3. Specifically couches question in terms of explaining why MS5's proposal made the most sense (Seq. 61, line 329)

1. This is the stoichiometric and Hannah admitted in past interviews that she liked about the name she picked
2. Seq. 71 Important discussion with MS1 and group about variables involved in testing, following by Hannah in line 239
Marty's Period 4 Lesson Solution Pathway Map, Pt. 2

1. FS4 line 233
   "Ones were non-metals and the ones react with more stuff"
   (Metals more reactive misconception?)
2. Marty line 234 revoking with slight re-formulation

1. MS1 line 236
   "Each element has to gain more valence electrons"
2. Revoking in line 237

1. MS2 line 239
   "Reactivity" and "need more space for valence electrons"
2. In Marty's revoking in line 240, he adds to their idea
   "need more space to take other people's electrons"

1. Connects to next-to-last group's idea in line 262,
   but doesn't really build on it
2. Coulombic effect in sequence 50
3. Magnet analogy in sequence 51
4. Key points made in lines 301, 303, and 307

1. MS16 lines 244 & 246
   "These gaining need more space than those losing"
   (Connects to previous group's idea)
2. No re-utterance by Marty

1. MS15 line 250
   "But, as you from right to left, the less"
   "your, uh, core is, the more you have to expand the outer"
   (Seems to be on the track of normative solution)
2. Important revoking by Marty in line 251

1. Lines 255, 256, & 258 by FS8 & FS9
   Number of electrons they can gain determines their size
2. Revoking by Marty in lines 259 & 261
Nancy's Period 6 Lesson
Solution Pathway Map, Pt. 1

Sequences 1-3
0:00-4:36
Connecting to Previous Lab
1. Remember to have periodic tables and books available
2. Builds up reaction from lab
3. Develops formula for magnesium chloride

Sequence 4
4.37-8:43
Building Up Problem
1. Reaction used in model rockets
2. Develops formula for product (zinc sulfide)
3. Poses problem in line 64

Sequences 5-6
8:44-9:45
Proposing 1st Solution
1. Interesting statement in line 65 by MS7
   ("I know they can't be equal.")
2. Offered by MS12 in line 68, but no update
3. Officially proposed in line 72 by MS9
4. Req. for just. in line 73 (not pursued as far as Pd.3)

Sequences 7-15
9:46-15:42
Cond. Test 1

Sequences 16
15:43-16:02
Analyze Test 1

Proposing Alternative Solution

1. First suggested in line 163 by FS13
2. Supported by MS6 in line 165

Expl. / Just.

Refute / Question
1. Given by MS8 in line 160
2. Explained justified in lines 170-180 (Look particularly at line 175)

More Sulfur

13.08 g.

Sequences 17-21
19:03-21:01

Less Sulfur

3.2 g.

1. Given by FS14 in line 164

Explain / Justify

Refute / Question
1. Line 188 is empirical refutation

Cond. Test 2

1. Originally, there is to be a vote over which proposal to test (line 195)
2. Then Nancy pushes for testing "3.2g." first (see lines 198 & 206)

From formalizing the solution
Nancy's Period 6 Lesson
Solution Pathway Map, Pt. 2

Sequence 28-40
41:22-45:44

Resetting
the Problem

1. Reviews formula
   for zinc sulfide
2. Reviews different
   solutions, justifications,
   and results of testing
   (Seq. 39-40)
3. Reviews explanation
   built so far (Sequence 40)

Formalizing
the Solution

1. Make relationships
2. Molar masses of compounds
3. Connection back to starting
   amount of zinc (1/10 of mole)
   and, through this, to the
   successful solution (but not
   either unsuccessful solution)
   (Connection is in sequence 44)

End of Day 1

Sequence 36-37
32:22-41:21

Return to Explaining
the Results

3. Avogadro's hypothesis
   (line 337)
4. Molecular Formulas mass (line 350)
   a. Molecular
   formula
   (Lines 372 & 374)
5. Connection to periodic table masses
   (Lines 382-393)
6. Need for a different scale (Line 397)
   and units for that scale (Line 396)
7. Avogadro's number (Line 407)

Explaining
the Results

1. "More is better"
   misconception addressed
   (Lines 289-291)
2. FS13: "Because
   it was almost half...")
   (Line 293)

Sequence 30
27:06-30:13

Cond. Test 3

Sequence 31-33
30:14-31:57

Cond. Test 4

Sequence 34
31:58-32:21
Sarah's Period 1 Lesson Solution Pathway Map

1. Rx used in model rockets
2. Rx very exothermic
3. Think about test until type of reaction
4. No discussion of process
   → Problem posed in line 2

Posing Problem

Develop List of 5

Sharing Out Prior Knowledge

Sharing out prior knowledge

Generating Solutions

Redox Reaction
3. Synthesis Rx
4. Coefficients
   → One atom of each reactant
   ionic/Polar covalent bond
5. 1 mole of each reactant
6. 1 mole Zn = 97g.

兑换 13:30-16:09

Begin by MS3 in turn 66; Cont. by him thru 78.
MS12 makes slight offset (line 80; position of decimal point);
FS1 finishes in 84:49.
(actual value given in 80)

Developing/supposing proposal

Analyzing Test 1

Formalizing the Solution

Analyze Test 2

Suggested in turn 179 by unknown male student;
in line 181, another male student says,
"Yeah, since that was one of our theories."

Line 194 ("Which do you think worked better?")
Line 195: Equal-Mass mixture;
Lines 194-201: Sarah presents definitive answer

Sequences:
1. 00:14-1:45
2. 1:46-4:16
3. 4:30-5:29
4. 5:30-10:00
5. 10:02-13:20
6. 13:30-17:34
7. 19:54-25:15
8. 25:16-25:20
9. 35:36-39:44
10. 38:42-40:35
11. 30:25-35:35
Sarah's Period 3 Lesson Solution Pathway Map

1. Sequence 1
   00:04-1:34
   Posing Problem
   - 1. Begins with discussion of how activity will be different
   - 2. Used in model rockets
   - 3. Rx is very exothermic

2. Sequences 2-5
   5:43-12:40
   Develop List of 5
   - 1. Sequence 5
     unknown mass suggests normative solution

3. Sequences 6-19
   5:43-12:40
   Sharing Out Prior Knowledge
   - 1. Zn and S are insoluble in H₂O (originally Zn and S are insoluble in water)
   - 2. Synthesis Rx
   - 3. Redox Rx (not addressed)
   - 4. Coefficients
     1 mole of each thing
   - 5. Molar masses of each thing
   - 6. S → Zn₂S (not addressed)
   - 7. Masses equal transformed into ??? if ??? of mass must be obeyed
   - 8. 2nd interpretation of coefficients: represent molecules (and atoms)

4. Sequences 20-25
   12:41-16:40
   Generating Solutions
   - 1. Proposed by MS in line 131 (sequence 23)
     different than pd. in that proposal procedure calculation
   - 2. Line 153: Sarah asks if students agree
   - 3. Sequence 24: student indicates he got some final answer but uncertainty about remainder of calculation

5. 13 g.
   Cond. Test 2
   Sequences 30-31
   19:50-21:31
   Sequence 33
   21:32-21:54
   Analyze Test 2
   Sequences 33-37
   21:55-25:55
   Formalizing the Solution
   - 1. Line 192: A couple of student statements in favor of mixture 1 (6.4 g)
   - 1. Much more in favor of mixture 1 (less uncertainty than Pd 1)

6. 6.4 g.
   Cond. Test 1
   Sequences 26-29
   19:41-19:44
   Sequence 29
   19:45-19:49
   Analyze Test 1
   Sequences 26-29
   19:41-19:44
   ** 1. Line 180: Sarah: “How many people think that was...?”

7. 1. Line 215: Sarah asks for explanation of both “good” and “bad” combinations
   2. Line 220: FSS offers explanation to account for both

Χ = Idea wasn’t accepted
★ = Idea was accepted
Sarah's Period 7 Lesson Solution Pathway Map

1. Mentions lesson essential question
2. Used in model rockets
3. Very exothermic
4. "Together as a class..." (line 3); small statement of process
5. Goes thru equation
6. References last unit on chemical reactions

Sequence 1
00:38-1:39
Posing Problem

Sequence 2-8
1:36-7:14
Develop List of 5

Sequence 9-14
7:15-12:19
Sharing Out Prior Knowledge

Sequence 15
12:20-13:56
Generating Solutions

Sequence 16-18
13:57-18:17
Proposing Solutions

6.37 g

Analyse
Test 1

1. Proposed by MS6 in line 114
2. Sarah makes Req. for alternatives in 117 before making req. for just/ieeab, in sequence 18 (Different from Pd. 1 and Pd. 3)

Cond. Test 1

1. Student in line 157
2. "I think it worked."
3. "Sarah in line 158: "You guys figured out..."

Cond. Test 2

1. Sarah proposes alternative in line 161 (sequence 24)
2. A couple of students indicate they would like to see this but there is no connection back to ideas they generated as happened in Pd. 1

Cond. Test 2

1. Line 197 Sarah connects back to first proposal and then asks why equal mass didn't work
2. Sequence 25-27 used to calculate and show why equal mass isn't good
3. Sequence 32 M&M analogy used to reinforce why stoichiometric mixture is better

Equal Mass

Formalizing the Solution

Sequences 19-22
16:18-19:39

Sequences 19-40
19:40-19:49

Sequences 25-27
20:01-22:52

Sequences 28
22:53-24:13

Sequences 29-34
24:14-30:40

= Idea wasn't accepted
* = Idea was accepted
Appendix H: Initial Discourse Function Code List for MSP Lesson Transcriptions

<table>
<thead>
<tr>
<th>Name of Function</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bid</td>
<td>Bid</td>
<td>Attempt to acquire speaking rights</td>
</tr>
<tr>
<td>2. Nominate</td>
<td>Nom.</td>
<td>Granting of speaking rights</td>
</tr>
<tr>
<td>3. Acknowledging Initiation</td>
<td>Ack. Initiation</td>
<td>Different than nomination in that it indicates implicit acceptance of speaker’s right to initiate a new (and unexpected) exchange</td>
</tr>
<tr>
<td>4. Acknowledge Request</td>
<td>Ack. Req.</td>
<td>Indicates that request has been recognized and will be answered</td>
</tr>
<tr>
<td>5. Request Repetition</td>
<td>Req. Rep.</td>
<td>When interlocutor asks previous speaker to repeat what s/he said</td>
</tr>
<tr>
<td>6. Repetition</td>
<td>Rep.</td>
<td>When speaker repeats what s/he said previously (following a request) or what previous speaker said to make sure it was heard properly</td>
</tr>
<tr>
<td>7. Request Information</td>
<td>Req. Info.</td>
<td>Speaker asks for a more specific fact (e.g. term, value of measurement) related to topic of discussion</td>
</tr>
<tr>
<td>8. Give Information</td>
<td>Give Info</td>
<td>Respondent provides a more specific fact that has been requested or is needed to advance the conversation</td>
</tr>
</tbody>
</table>
Information

expresses agreement / disagreement with information offered and provides rationale for this

10. Request Confirm. ➔ Req. Confirm. ➔ Speaker asks others whether the information just given is correct

11. Give Confirmation ➔ Give Conf. / Disconfirm. ➔ At speaker’s request, interlocutor indicates that information provided is correct / incorrect

Disconfirmation

12. Request Idea / Proposal ➔ Req. I / P ➔ Speaker asks for answer from a more wide-open set of responses (than Req. Info.), particularly related to the solution to a problem

13. Give Idea / Proposal ➔ Give I / P ➔ Respondent offers an idea / proposes a solution to a problem

14. Support / Refute Idea / Proposal ➔ Sup. / Ref. I / P ➔ Speaker shows agreement / disagreement with previous idea by offering info / evidence for / against it

15. Modify Idea / Proposal ➔ Mod. I / P ➔ Speaker makes suggestion which doesn’t undermine main idea of her/his own / another’s proposal but suggests some change in it

16. Request Selection of Proposals ➔ Req. Sel. Prop. ➔ Speaker asks for respondents to choose which of a set of proposals
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Give Selection of Proposals</td>
<td>⇒</td>
<td>Give Sel. Prop.</td>
<td>⇒</td>
</tr>
<tr>
<td>18. Request Clarification</td>
<td>⇒</td>
<td>Req. Clarif.</td>
<td>⇒</td>
</tr>
<tr>
<td>19. Give Clarification</td>
<td>⇒</td>
<td>Give Clarif.</td>
<td>⇒</td>
</tr>
<tr>
<td>20. Request for Elaboration</td>
<td>⇒</td>
<td>Req. Elab.</td>
<td>⇒</td>
</tr>
<tr>
<td>21. Give Elaboration</td>
<td>⇒</td>
<td>Give Elab.</td>
<td>⇒</td>
</tr>
<tr>
<td>22. Request for Justification</td>
<td>⇒</td>
<td>Req. Just.</td>
<td>⇒</td>
</tr>
<tr>
<td>23. Give Justification</td>
<td>⇒</td>
<td>Give Just.</td>
<td>⇒</td>
</tr>
</tbody>
</table>
24. Request for Prediction ➔ Req. Pred. ➔ Speakers asks other participant(s) for expected outcome of upcoming / potential event

25. Give Prediction ➔ Give Pred. ➔ Respondent(s) describe expectations concerning outcome of upcoming / potential event

26. Request for Evaluation of Results [Overall] ➔ Req. Eval. Res. [Over.] ➔ Speaker asks other participant(s) for appraisal of results of some test / analysis that has been conducted [Overall in case of request for broad analysis of set of tests]

27. Give Evaluation of Results ➔ Give Eval. Res. ➔ Respondents provide appraisal of results of test / analysis conducted [Overall in case of broad analysis]

28. Support / Refute ➔ Supp. / Ref. Eval. Res. ➔ Speaker shows agreement / disagreement with the evaluation of a result by previous speaker

29. Request Critical Analysis ➔ Req. CA ➔ Speaker asks other participants to examine the validity of ideas that are ‘on the table’

30. Give Critical Analysis ➔ Give CA ➔ Respondent offers an assessment of the validity of ideas / proposals that are ‘on the table’
31. Request for Re-Explanation  ➔  Req. Re-Expl.  ➔  Speaker asks one participant to re-explicate an idea given by a different participant

32. Give Re-Explanation  ➔  Give Re-Expl.  ➔  Respondent re-explicates (or attempts to) an idea given by a different participant

33. Unable to Meet Request  ➔  Un. Meet Req.  ➔  Respondent is unable to provide info, idea, clarification, justification, etc. requested in reply

34. Make Assertion  ➔  Make Assert.  ➔  Speaker makes a claim about a piece of information representing valid [scientific] knowledge

35. Support / Refute Assertions  ➔  Supp. / Ref. Assert.  ➔  Speaker indicates that previous speaker’s assertion is valid / invalid

36. Defend Position  ➔  Def. Pos.  ➔  Speaker responds to criticisms / refutations of his / her ideas with arguments supporting original position

37. Make a Suggestion  ➔  Make Sugg.  ➔  Speaker proposes something other than idea related to solving a problem such as how to conduct a test, etc.

38. Accept / Reject Suggestion  ➔  Acc. / Reject Sugg.  ➔  Respondent accepts / rejects proposal made by speaker

39. Re-utterance Sub-Types
a. Re-Utterance with RU w/ Full Int. Speaker largely re-states the main Full Integrity idea(s) in previous response pretty much verbatim

b. Re-Utterance with RU w/ Conf. Speaker re-states part of previous Confirmation response as means of validating response
c. Re-Utterance with RU with Eval. Speaker re-states part of and then Evaluation and then adds on a judgment of of validity / quality
d. Re-Utterance for RU for CA Speaker re-states part of previous Critical Analysis response as a way to hold it up for further examination by participants
e. Re-Utterance with RU w/ Req. Clar. Speaker re-states part of previous Request for Clarification response and asks for elucidation
f. Re-Utterance with RU w/ Req. Elab. Speaker re-states part of previous Request for Elaboration response and asks for expansion on ideas / more information
g. Re-Utterance with RU w/ Req. Just. Speaker re-states part of previous Request for Justification response and asks for reasoning behind this response
h. Re-Utterance with RU w/ Req. Ver. Speaker re-states part of previous Request for Verification response and asks for confirmation from other speakers of validity
i. Re-Utterance with RU w/ Expan. ➔ Speaker re-states part of previous response and then adds info to it

j. Re-Utterance with RU w/ Connect. ➔ Speaker re-states part of previous response and connects it to other salient points to build a more complete / clear idea

k. Re-Utterance with RU w/ Comp. ➔ Speaker re-states part of previous response and compares it to other ideas that have been presented

l. Re-Utterance with RU w/ Cog. Sup. ➔ Speaker re-states part of previous response to help previous speaker build up or complete idea / proposal

m. Re-Utterance with RU w/ Sup. Info. ➔ Speaker re-states part of previous response and adds a point(s) that seem to back the idea(s) contained in the previous response

n. Re-Utterance with RU w/ Summar. ➔ Speaker re-states part of previous response(s), but abbreviates it in a way that allows it to represent a concise, summary re-statement.

o. Re-Utterance with RU w/ Re-Form. ➔ Speaker re-states part of previous response, but changes the language or content in some noticeable way
40. Call for Affirmation ➔ Call Affirm. ➔ Following a true re-voicing move, speaker asks for indication of proper re-voicing from speaker whose ideas were being re-voiced (re-uttered)

41. Give Affirmation / Disaffirmation ➔ Give Affirm. / Disaffirm. Previous speaker indicates that re-voicing does / does not capture intent of her / his original statement

42. Show Agreement / Disagreement ➔ Show Agree. / Disagree Speaker shows support for / refutes a previous speaker’s idea / proposal without elaborating on why the support / refutation is given

43. Check for Common Understanding ➔ Check Com. Under. Speaker asks respondent if s/he understands what speaker has said or understands in same way as speaker (e.g. “Do you know what I mean?”)

44. Show Common Under. ➔ Show Com. Under. Respondent presents ideas to indicate that s/he does / does not possess common understanding (If s/he does not, [No] will be placed between ‘Show’ and ‘Com.’)

45. Check for Mutual Understanding ➔ Check Mut. Under. Speaker (usually teacher) asks other participant(s) whether they understand an idea
46. Confirm. / Disconfirm. → Conf. / Disconf. → Respondent(s) indicate understanding or lack thereof with regard to previous speaker’s ideas

47. Acknowledge Uncertainty → Ack. Unc. → Individual indicates that something in the discussion (including some aspect of her/his thinking) is unclear

48. Seeking Understanding → Seek. Und. Quest. → Asked when individual truly does not have comprehension of topic of question

49. Indicate Error → Ind. Err. → Speaker (likely teacher) points out where a mistake has been made in a process, such as a calculation

50. Correct Previous → Correct Prev. → Respondent fixes a mistake made in a prior turn, often after previous speaker has indicated the mistake

51. Withhold Feedback → W-hold Feed. → Instead of giving evaluation to previous response, speaker initiates another exchange related to the content of that response

52. Acknowledge → Ack. → Interlocuter indicates that s/he has heard the previous speaker’s statement but does not clearly indicate acceptance of it
53. Acceptance ➔ Accept. ➔ Allow that info given by previous speaker may be valid without confirming or evaluating (for instance by using it in follow-up)

54. Appraisal ➔ Appr. ➔ Offer judgment about response / info / idea given beyond simply indicating it is correct or incorrect (such as “That’s good”)

55. Reifying Contribution ➔ Reify. Contr. ➔ Some act – such as writing down info / idea / proposal that treats it as formally accepted and part of available knowledge base

56. Bestow Clue ➔ Bestow Clue ➔ Provide hint about how to solve problem / answer question

57. Identify Distinction ➔ Ident. Dist. ➔ Speaker points out a difference between ideas that may otherwise have been considered to be similar

58. Address Norm ➔ Address Norm ➔ Speaker’s move is focused on norms of classroom beyond just requesting application of specific norm

59. Summarize Point ➔ Summ. Point ➔ After a significant amount of info is presented, the speaker sums it up in one succinct statement
<table>
<thead>
<tr>
<th></th>
<th>Humorous</th>
<th>Humorous</th>
<th>Respondent makes comment that makes light of situation compared to the expected type of response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Digression</td>
<td>Digress.</td>
<td>Respondent gives reply that takes conversation away from the ideas intended in previous turns</td>
</tr>
</tbody>
</table>
Appendix I: Final Discourse Coding Scheme for MSP Lessons

I. Essential Code Set for Progressive Discourse Commitments

A. Mutual Understanding

1. Request // Give Clarification / Elaboration [Req. // Give C / E]

   a. Used whenever a speaker asks for or provides information that either
      helps elucidate some aspect of ideas under discussion or represents
      additional details related to an idea or a statement previously made.
      This is expected to be a relatively common move in the whole-class
      discussion as speaker’s are likely to offer either very abbreviated or very
      cryptic discussions of their ideas initially and other speakers will need to
      elicit further information from them. It is important to note also that
      while the Request and Give will often occur in an I – R pair, it is
      possible that a speaker (likely a teacher) will conduct a Give C / E that is
      unsolicited (e.g. as part of a follow-up move).

   b. Example 1 (from Sarah’s period 1 class):

      | Discourse | Exch. | Move | Function |
      |-----------|-------|------|----------|
      | Sarah [5:30]: Okay, I’m just going to call on some people and I’m going to write some stuff down up here [points to transparency]. Um, let’s see. [MS 3], what’s one thing? | Nuc. | I | Req. I / P |
      | MS 3: ‘Redox’. | Nuc. | R | Give I / P |
      | Sarah: Okay, it is a ‘redox reaction’. [Writes this on transparency.] How do we know it’s a redox reaction? [MS 4]. | Nuc. | F | Reify Contr. |
      | Sarah: It’s a ‘synthesis reaction’. | Dep. | R | Give C / E* |
      | [*This seems to be just an additional piece of information; however, these students have been...| Dep. | F | Appr. |
taught that a synthesis reaction will always be a redox reaction and that’s what makes it a

Give C / E.]

c. Example 2 (from Sarah’s period 7 class, right after the first solution has been proposed)*:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarah:</td>
<td>Nuc.</td>
<td>I</td>
<td>Req. C / E</td>
</tr>
<tr>
<td>MS 7:</td>
<td>Nuc.</td>
<td>R</td>
<td>Give C / E</td>
</tr>
</tbody>
</table>

Sarah: Okay, I wanna know how you guys got ‘6.4 grams’. [MS 7].

MS 7: Um, you take the ‘13 grams’ of zinc [pause as Sarah is writing this down in a calculation] . . . and divide it by the molar mass of zinc to find out how many moles there are. Then, you multiply that . . .

[*This second example is included to show that after a proposal has been made by a student, the teacher may not necessarily use a Req. Just. move, but might use a Req. C / E move. How to code this was based on language and context. In her classes, Sarah was more interested in students displaying their ability to conduct certain calculations than getting them to defend their proposals. Additionally, her language in the initiation move shows that this is what she is really after.]

2. Request // Give Re-Explanation [Req. // Give Re-Expl.]

a. Used whenever a participant (invariably, the teacher) asks a participant to repeat or restate an idea (or justification or elaboration) that has already been put out there. This is not an immediate repeating of an idea by the person who originally proposed it for clarification purposes. This is either that person repeating it at a much later time in the class (as occurred in Hannah’s period 4 class) or another person being asked to recount that idea.

b. Example (from Sarah’s period 1 class)*:
Sarah [16:12]: Um, let’s see [pause] . . . [FS 10]. Why do you think she did that [referring to a calculation described by another student]?

FS 10: Um, because [several second pause] . . . yeah, because she’s a genius [responding to a prompt from another student]!

[Students laugh]

FS 10: No, because you have to, like, multiply them together to get ‘ZnS.’

Sarah: Okay.

FS 10: I don’t really know how to explain it. Like, I understand why she did it, I just don’t know how

Sarah: Okay.

[*This example was chosen because it was a little less straightforward than some others.

It was coded as Req. Re-Expl. because Sarah asked FS 10 to provide insight into why a calculation was done a certain way by another student. While one could argue that this was a Req. C / E, it seems clear that Sarah wants to make sure the other students understand what the person explaining the calculation is doing.]

B. Expansion

1. Request // Give Idea / Proposal [Req. // Give I / P]

a. To keep the integrity of this code, its use is reserved for either (1) those ideas / proposals which are directly related to solving the problem or (2) those ideas / proposals that address challenges confronted in the attempt to solve the problem (such as why empirical tests are not giving consistent results). A unique form of Req. I / P occurs in Hannah’s classes where she asks for revisions to their I / P (see Sup. // Mod. // Ref. I / P for further discussion of this).
b. Example (from Marty’s period 4 class)*:

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marty: What order did you put them in? [Reminding them] Smallest up to biggest.</td>
<td>Nuc.</td>
<td>I</td>
<td>Req. I / P</td>
</tr>
<tr>
<td>FS 10 [member of back corner lab group]: ‘Be’. [Beryllium]</td>
<td>Nuc.</td>
<td>R</td>
<td>Give I / P</td>
</tr>
<tr>
<td>FS 10: ‘Ca’. [Calcium]</td>
<td>Nuc.</td>
<td>R</td>
<td>Give I / P</td>
</tr>
<tr>
<td>FS 10: And ‘Ba’. [Barium]</td>
<td>Nuc.</td>
<td>R</td>
<td>Give I / P</td>
</tr>
</tbody>
</table>

[*This example was chosen because it represents another complicated case. The I / P Marty is looking for is what the trend is down a family, and that idea is presented over 11 turns which alternate between Marty making a Req. I / P and FS 10 presenting a piece of a larger Give I / P.]

2. Request // Give Alternatives [Req. // Give Alt.]

a. The idea behind this code was to look for specific instances in which a participant (usually the teacher) clearly sought to expand the set of ideas / proposals under consideration. This was not meant to represent a case in which the teacher required that every group come up with their own idea and then went from group to group asking each group to share out their idea – that could be captured by Req. // Give I / P. This was meant
to include instances below where students have a chance to come up with ideas, an idea is presented and talked about, and then other ideas are considered as true alternatives to the original proposal.

b. Example (from Sandy’s period 1 class):

<table>
<thead>
<tr>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy: All right. So, how much are we going to use?</td>
</tr>
<tr>
<td>Unknown male student: Same amount [of sulfur as zinc].</td>
</tr>
<tr>
<td>Another male student: &lt;‘6.54 grams’.</td>
</tr>
<tr>
<td>Sandy: &lt;Same amount. ‘6.54’.</td>
</tr>
<tr>
<td>Anybody come up with a different number?</td>
</tr>
<tr>
<td>[No response]</td>
</tr>
<tr>
<td>Sandy: All right, ‘6.54 grams’. [Writes this on board]</td>
</tr>
<tr>
<td>Why?</td>
</tr>
<tr>
<td>Male student who offered amount: Because it’s balanced.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuc. I</td>
<td>Req. I / P</td>
<td></td>
</tr>
<tr>
<td>Nuc. R</td>
<td>Give I / P</td>
<td></td>
</tr>
<tr>
<td>Nuc. R</td>
<td>Give I / P</td>
<td></td>
</tr>
<tr>
<td>Nuc. F</td>
<td>RU</td>
<td></td>
</tr>
<tr>
<td>Dep. I</td>
<td>Req. Alt.</td>
<td></td>
</tr>
<tr>
<td>Dep. R</td>
<td>Give Just.</td>
<td></td>
</tr>
</tbody>
</table>

C. Openness

1. Request // Give Justification [Req. / Give Just.]

   a. Used in cases where a speaker asks for or provides a rationale for an idea / proposal that was made or why that proposal is valid and should be given further consideration. The one challenge in coding has been to distinguish this from instances of Req. // Give C / E. Again, the key clues are language and context. With regards to language, there is a need to be cautious because it would be easy to code any utterance that involves a ‘Why?’ question as a Req. Just. However, as Sarah’s first turn in the Req. Re-Expl. example showed, the presence of such language does not automatically indicate a Req. Just. That is where
context becomes important. For instance, in both Nancy’s and Marty’s classes, it was made very explicit in the Building Up the Problem section that students were going to have to justify their proposals, and so it was almost always the case that in any dependent exchanges following a proposal, there would be a Req. // Give Just. pair.

b. An example (from Nancy’s period 6 class):

<table>
<thead>
<tr>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nancy [9:21]: [MS 9], what did you say?</td>
</tr>
<tr>
<td>How much do you think?</td>
</tr>
<tr>
<td>MS 9: ‘6.54 grams’.</td>
</tr>
<tr>
<td>Nancy: ‘6.54 grams’. [5 seconds pause while she gets new marker to write on board and writes this value down under ‘S’] So he wants me to try ‘6.54 grams’. And why do you say that, [MS 9]?</td>
</tr>
<tr>
<td>MS 9: Because they both have two: one’s plus two, one’s minus two and I just reduced the numbers.</td>
</tr>
<tr>
<td>Nancy: Okay. So if they go together in a one-to-one ratio, go together in a one-to-one ratio. Okay.</td>
</tr>
</tbody>
</table>

2. Request Evaluation [Req. // Give Eval.]

a. Used for all cases in which one participant asks another to provide an examination of an idea presented, or, more generally, the content of a previous utterance. That can include instances such as when a student asks a teacher if the student’s idea is ‘wrong’ or not.

b. Example (from Hannah’s period 1 class):

<table>
<thead>
<tr>
<th>Discourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hannah [28:10; to FS 6]: What are you thinking?</td>
</tr>
<tr>
<td>FS 6: I don’t know. I think it’s going to be too much [sulfur].</td>
</tr>
<tr>
<td>Hannah: And so, what will happen?</td>
</tr>
</tbody>
</table>
FS 6: (Inaudible, but she does say something to the effect to “I think it’s going to die”)  Dep.  R  Give Pred.

[*This is an interesting example because Hannah’s initiation move is ambiguous in terms of what she is really looking for. However, since FS 6 gives a response which brings into question the validity of an idea that is – at the point this pair of exchanges occurs – in the testing phase, then FS 6 has treated Hannah’s initiation as a Req. Eval.]

   a. This code and the one that follows are designed to be used to code responses to Req. Eval., although both can be used in situations where there is not such a request. In other words, if there is a Req. Eval., this code or the next one will be used to mark the response that follows (assuming it is discernible and is a reasonable reply), but either code can happen without such an initiation. The Sup. // Mod. // Ref. I / P code will be employed when it is the idea itself, and not the reasoning behind it that is being considered in the evaluation. This can include an idea that is part of a clarification or elaboration. While it may seem like it would be hard to parse out an evaluation of the idea itself from an evaluation of the reasoning behind it, there were enough examples in the corpus where this distinction seemed valid to keep the two different codes in tact.

A challenging aspect of this came in cases where it seemed that students may be giving justification related to an idea that is out there. The decision was made to use Sup. I / P if that justification was related to someone else’s idea (made by a student in a subsequent turn) or it was a
person defending her / his own idea against a criticism that had been lodgest against it.

One issue related to this code is unique to Hannah’s classes where she had a task segment – Revising the Plans – that was not found in any of the other lessons. During this segment, she would ask groups for their ‘Revisions Plans’ – i.e. based on what they had seen in the investigation so far, were they going to make changes in their original proposal.

While Hannah’s initiation move was simply coded Req. I / P, a decision was made that the response would not simply be coded Give I / P, but would be given one of these three codes. If the respondent indicated that s/he would be sticking with their original idea, it was coded Sup. I / P (of their original idea); if the respondent indicated it would be changed, but didn’t talk about the identification of a particular flaw that lead to the change, then it was coded Mod. I / P; and if there was some kind of statement indicating that something had been identified as being wrong with the original idea, then it was coded Ref. I / P.

b. Example (from Nancy’s period 6 class):

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nancy: . . . we’ve got some people saying, ‘I think higher’,</td>
<td>Nuc.</td>
<td>I</td>
<td>Req. I / P</td>
</tr>
</tbody>
</table>
| we’ve got some people saying, ‘I think lower’. So let’s just go . . . let’s try someone who said ‘higher’ first.  
  All right, so . . . how much higher?                                      |       |      |                |
| MS 8 [18:48]: ‘13.08’.                                                     | Nuc.  | R    | Give I / P     |
| And <how did you come up with that number?                                | Dep.  | I    | Req. C / E     |
| FS 13 [almost as a response to MS 8’s value]: <I was                     | Emb.  | I    | Give I / P // Ref. I / P |
thinkin’ like ‘10’ [grams of sulfur].

MS 8: <<I multiplied it by two.

Unknown male student: <<Yeah, you’re thinking, like, ‘10’.

Nancy: Okay, so you multiplied it by two. For any reason?

MS 8: Because the weight of zinc is heavier than sulfur.

Nancy: So the weight of zinc is heavier [1 second pause] . . . <than the weight of . . . the weight of zinc is heavier than the weight of sulfur, <<so you think you need more of this [the sulfur].

Unknown male student: <Isn’t it twice as much?

MS 7 [to unknown male student]: <<Approximately.

MS 8: About two times.

Nancy [about 4 seconds later after writing some info on board]: Okay. [2 seconds pause]. So you’re gonna end up [2 second pause as she looks at what she has written; throws both hands up] Okay [looks over towards camera]. All right. So the weight of zinc is heavier so we’re gonna double it. All right, so let’s [hand gesture towards MS 8] . . . I understand that – I understand that concept. Okay.

Unknown male student [19:30]: That’s a lot of sulfur.

Nancy: It is a lot of sulfur.


a. This was designed to provide the other code for responses to a Req. Eval., but, again, can occur without that initiating move preceding it. In this case, the evaluation is more focused on some aspect of the logic related to an idea, such as the justification, elaboration, another evaluation, the analysis of a result (see last code), etc. The approach taken was that if one individual simply said that s/he didn’t like something presented by another individual, but weren’t specific about what s/he didn’t like, the previous code was used; for this code to be
employed, there had to be specific reference to the reasoning of the
previous speaker.

b. Example (from Marty’s period 6 class which occurs after a group has
indicated their prediction of the trend across a period and begins with a
member of that group – FS 7 – offering her explanation for why this was
their prediction):

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS 7: And sometimes they increased in electrons, but</td>
<td></td>
<td>I</td>
<td>Give C / E</td>
</tr>
<tr>
<td>sometimes they stayed the same.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marty: Okay, sometimes they increased the number of</td>
<td></td>
<td>R</td>
<td>Accept.</td>
</tr>
<tr>
<td>electrons and sometimes they stayed the same.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[About a 3 second pause] So that is . . .</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS 2: Wait, I’m confused.</td>
<td></td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>Unknown female student: So am I.</td>
<td></td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>FS 2 [directed at Marty]: Isn’t the number of protons and</td>
<td></td>
<td>I</td>
<td>Req. C / E</td>
</tr>
<tr>
<td>the number of electrons the same?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marty: Yes.</td>
<td></td>
<td>F</td>
<td>Give C / E</td>
</tr>
<tr>
<td>FS 2 [directed at Marty]: So how is it that the protons</td>
<td></td>
<td>I</td>
<td>Ref. Reas.</td>
</tr>
<tr>
<td>can increase but the electrons don’t?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS 7 [responding to this]: Okay, then it was the neutrons</td>
<td></td>
<td>R</td>
<td>Mod. Reas.</td>
</tr>
<tr>
<td>that stayed the same.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marty [also responding to this]: They can’t.</td>
<td></td>
<td>R</td>
<td>Accept.</td>
</tr>
</tbody>
</table>

D. Empirical Testability

1. Request // Give Prediction [Req. // Give Pred.]

   a. Used when a speaker asked for or provided a statement representing an
      expectation of what was going to happen when the empirical test of a
      particular solution was conducted.

   b. Example (from Hannah’s period 4 class):
Discourse  |  Exch.  |  Move  |  Function
---|---|---|---
Hannah: Um, [FS 6], you know how you’re group had a different amount. What do you think this amount’s gonna do? | Nuc. | I | Req. Pred.
MS 5: (Inaudible, but something related to there being too much S) | Dep. | R | Give Just.

2. **Request // Give Observation [Req. // Observ.]**

   a. Used when a speaker asks for or provides a description of what occurred during an empirical test of a solution. An important issue related to this code is how to handle statements by students such as, “It was crappy” to describe a test that produced unimpressive results – the statement has an evaluative nature to it. It was decided, though, that such statements very often do represent observations in the minds of the students who utter them, and so the coders tried not to impose their views of what constitutes a legitimate scientific observation when coding for this (and the next) category.

   b. Example (from Sandy’s period 1 class) will be presented after the next code category to show the distinction between the two codes.


   a. Used when a speaker asks for or provides any kind of evaluation of the results of a test, such as comparing the results for a sample just tested to those for a sample tested previously, ranking samples in terms of the quality indicated by the test results, or discussing what the test suggests about the efficacy of a sample as a solution to the problem. One
problem with the description just given is that an utterance like, “That burned really well” certainly has an evaluative note to it, but the coders need to keep in mind who it is that will be making such utterances – students – and that, for them, evaluations are often a natural part of their observations (even if that does make them seem less than scientific).

b. Example (from Sandy’s period 1 class):

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy: Okay, so what do you see from the reaction?</td>
<td>Nuc.</td>
<td>I</td>
<td>Req. Observ.</td>
</tr>
<tr>
<td>Same male student as 72 &amp; 75: Blue.</td>
<td>Nuc.</td>
<td>R</td>
<td>Give Observ.</td>
</tr>
<tr>
<td>Male student near him: Yeah, I see blue.</td>
<td>Nuc.</td>
<td>R</td>
<td>Give Observ.</td>
</tr>
<tr>
<td>Sandy: Blue – you see a blue fire.</td>
<td>Nuc.</td>
<td>F</td>
<td>Ack.</td>
</tr>
</tbody>
</table>

III. Re-Utterance [RU]

A. As noted in the Methods chapter, this was designed to be a replacement for O’Connor and Michaels notion of *revoicing*, which could overcome some of the limitations of the structural definition that they have chosen for that term. As it was described in that chapter, the re-utterance move involves the circumstance in which one speaker re-states all or part of a previous speaker’s utterance in a manner which contributes to a deeper understanding of the original utterance or a deeper scrutiny of its content. In other words, a re-utterance isn’t a simple ‘parroting’ of what a prior interlocutor has said (such as when a teacher does this as a means of evaluation) – it has to support genuine progress in the discourse. Additionally, it needs to be pointed out that the re-utterance needs to occur
in close temporal proximity – within just a few discourse turns – of the previous speaker’s statement or the move would be acting as an *intertextual reference*.

B. Example 1 (from Nancy’s period 6 class at the point at which a proposal has been made and Nancy is asking the student who made it to support that proposal):

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>All right, shh, shh-shh, shh! Let’s listen to [FS 14].</td>
<td>Emb.</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>FS 14: Because it’s the atomic mass divided by ten.</td>
<td>Dep.</td>
<td>R</td>
<td>Give Just.</td>
</tr>
<tr>
<td>Nancy: The atomic mass divided by ten.</td>
<td>Dep.</td>
<td>F</td>
<td>Accept.</td>
</tr>
<tr>
<td>FS 14: &lt;Because zinc’s atomic mass divided by ten is ‘6.54’.</td>
<td>Dep.</td>
<td>R</td>
<td>Give Just.</td>
</tr>
<tr>
<td>Nancy: Okay, so the atomic mass of zinc is ‘65.4’ and she says, ‘Well, I started with the atomic mass [of zinc] divided by ten, so I’m gonna go with the atomic mass [of sulfur] divided by ten.’ Because the atomic mass of zinc . . . or, sulfur, is like 32.</td>
<td>Dep.</td>
<td>F</td>
<td>RU*</td>
</tr>
</tbody>
</table>

[*This is re-utterance in which Nancy attempts to create a deeper conceptual understanding of FS 14’s idea by adding a piece to the chain of logic that FS 14 developed in her two turns (that she had done the same division by ten with sulfur that she had done with zinc).]

C. Example 2 (from Marty’s period 4 class when a group is presenting their prediction about the trend down a family and the reasoning behind it; it is important to note that a couple of other groups have presented the same information prior to this excerpt):

<table>
<thead>
<tr>
<th>Discourse</th>
<th>Exch.</th>
<th>Move</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marty: So, as they went down – bigger or smaller?</td>
<td>Dep.</td>
<td>I</td>
<td>Req. C / E</td>
</tr>
<tr>
<td>[No response initially]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marty: As you went down . . .?</td>
<td>[Rep. Dep. – I from above, Req. C / E]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS 11 [ with FS 12 make a hand gesture indicating they]</td>
<td></td>
<td>R</td>
<td>Give C / E</td>
</tr>
</tbody>
</table>
got bigger]: Oh, bigger.

Marty: As they go down, they went bigger.  

Is that the same as the other group?  

FS 11: Yeah.  

Marty: Yeah.  

Why did you say that?  

FS 11: Uh . . . because the protons increased as we went farther down.  

Marty: Okay. They said – not because of *orbits* – but because the number of protons increased, it got larger.  

[*What makes this second example an RU and not just a parroting of what FS 1 said is that Marty makes a comparison between what this group said – the atoms get bigger down a family because of an increase in protons – and what a previous group had said – that the atoms get bigger down a family because of there being more orbits. That comparison means that the two ideas are both being held up for further examination – in this case, against each other.]
Appendix J: Discourse Coding of Sandy’s Pd 3 Lesson

Discourse   Exchange   Move   Function

B. Offering the First Solution [Begins at 4:16]

Sequence 3

35. Sandy [continuing from line 34]: Now, to start with, we need an amount, and I have chosen ‘6.54 grams’ of zinc. [Writes on board.]

So you need to decide some number of grams of sulfur that will make this reaction work the best. [Writes ‘___ g S’ to represent the problem.]

So, what do you think that would be? Nuc. I Req. I / P

36. MS 1 [4:18]: ‘6.54’ Nuc. R Give I / P


38. MS 6: Yeah. Dep. R Sup. I / P*

39. MS 7: Yep. Dep. R Sup. I / P*

[*These students respond so quickly that it is clear that they did not really critically examine this idea.]

D. Analyzing the Test I [Begins at 8:46]

Sequence 8

68. Unknown male student: Yeah. [Sarcastic] 

69. Unknown female student: I’m gonna say, ‘No.’ 

70. MS 1: A really small one. 

71. Sandy: No, it’s kind of small. It’s kinda glowing – it’s got a purplish glow to it. 

   But is that really the ‘ka-boom’ you were hoping for? 

72. A couple of students: No. 

73. Sandy: No. 

74. MS 7 [9:04]: You add more. [Sandy does not respond to this.] 

E. Explaining the Dead End . . . Interrupted [Begins at 9:05] 

   Sequence 9 

75. Sandy: No. [Cont. of Dep. – F from line 73; SER] 

   So what must be true about why – why do you think it didn’t work? 

[This is really important because it is an example of a teacher trying to get students to learn from a dead end moment.] 

76. Unknown female student: We need more of the zinc stuff. 

[This is really important because instead of answering Sandy’s question, the student is merely proposing a different solution.]
77. Sandy: You need more of something – well, which one?  Nuc. F [Partial] Sup. I / P

[***It is interesting that Sandy turns to the rest of the class in stating this. Also, she has not pushed the students to do something more than just offer other alternatives.]

78. A couple of students: Both.  Dep. R Give I / P

79. FS 3 [9:16]: No [to suggestion of both].  Dep. F Ref. I / P

The sulfur.  Dep. R Give I / P

80. A couple of other female students: The sulfur.  Dep. F Sup. I / P

81. A couple of male students: The zinc.  Dep. R Give I / P


Okay, well, how are you going to figure out which you need more of?  Dep. I Req. I / P****

[****This is really important as an attempt by Sandy to have them move beyond just guessing.]

83. MS 7: Light ‘em both on fire.  Dep. R Make Sugg.

84. Unknown female student: Keep testing it.  Dep. R Give I / P


[****This is really, really important because Sandy is trying to get them to move beyond ‘trial-and-error’ testing.]

86. Several students: Yeah. Yep.  Dep. R Sup. I / P
87. Sandy: Is random testing scientific?  
88. Several students: No, it’s . . .

F. Revisit Analyze Results I [Begins at 9:35]

**Sequence 10**

89. [The students’ response is interrupted (9:35) by the mixture igniting and burning up.]

90. FS 3: Like, ‘Surprise!’

91. MS 1: *Now* it’s enough to fuel a rocket.

92. MS 7 [9:49]: How did that happen all of a sudden?  

93. Unknown female student: Spontaneous combustion.

94. Sandy [9:58]: All right.

   So, was this reaction *dependable*?

95. Several students: No.

96. Sandy: No.

   If you are fueling a rocket, do you want it to be random like that?

97. Several students: No.

98. Sandy [10:05]: No.
You want it to work \textit{when you want it to work}. Okay, it didn’t go
right away [mixture flares up while Sandy is saying this] . . . it’s just . . .

99. FS 1: That’s a pretty flame. 

100. Sandy: Yes, it is a pretty flame. [A short pause] All right. Now, maybe it will flare up again [which it does] . . . Hey, on cue!

G. Returning to Explaining the Dead End and Proposing an Alternative [Begins at 10:34]

\textit{Sequence 11}

101. Sandy: Now, the reaction didn’t work as well as you wanted
it to the first time. If you get the \textit{right mix}, it will go \textit{the first time},
very quickly, \textit{and it won’t} keep, you know, dying out and coming
back, dying out and coming back. Because you don’t want . . .

If you’re baking a cake, you want it – when you put it in the oven,
you want it to just keep cooking. You don’t want to have to keep
taking it out and putting it in, taking it out and putting it in, taking
it out and putting it in, because it’s not going to rise and get all nice.

So you want it to go correctly \textit{the first time} and this is where the
math comes from. So, equal grams of zinc and sulfur won’t work. But it is a ‘one-to-one ratio’ in the balanced equation.

Let’s see why this doesn’t work. If you add ‘6.54 grams’ of zinc to ‘6.54 grams’ of sulfur, how many grams of zinc sulfide are you going to get?


103. Sandy: Okay, so you’re going to have ‘13+ grams’ of zinc sulfide.

All right, ‘13+’ – more than ‘13.’ Okay, because I ran out of space, plus I can’t do all of that math. Good thing I went to school before the math PSSA’s.

104. [Students laugh]

105. Sandy: Okay, so you’ve got more than ‘13.’ Now, there should be some things that aren’t sitting right with you with this number.

How did you choose this ‘6.54’ [for sulfur]?

106. FS 3: It was a ‘one-to-one’ ratio.

107. Sandy: It was a ‘one-to-one.’

So if that’s a ‘one-to-one,’ what should this number be
[referring to mass of product]?

108. Several students [12:15]: ‘6.54’.


But can that number be ‘6.54’?

110. A couple of students: No.

111. Sandy: No, because of what law?


So if you have six-and-a-half grams of something, and you add it to six-and-a-half grams of something else, and nothing else gets destroyed, it [the mass of the product] has to be over ’13’. Okay, it’s not going to be ‘6.54.’ So there’s one reason that doesn’t work: It doesn’t follow the Law of Conservation of Matter.

Sequence 12

114. Sandy: Also, if you look on the smallest level – if we look on the smallest level at what is happening with our Super
Chem Goggles, this is ‘1’ what of zinc combines with one what of sulfur?

115. MS 1 [13:02]: Atom. Nuc. R Give C / E


And this [pointing to product] is one formula unit which looks just like a molecule. All right, so this is ‘one atom of zinc’ reacts with ‘one atom of sulfur’ gives you ‘one formula unit of zinc sulfide.’

Are zinc and sulfur the same thing?

118. A couple of students: No. Dep. R Give C / E


What’s different about zinc and sulfur?

120. FS 11 [13:35]: They’re in different places on the periodic table. Dep. R Give C / E

121. Sandy: They’re different on the periodic table, they’re different elements, they’re different atoms, and since they’re different places on the periodic table, what’s going to be true about they’re masses?

Dep. I Req. C / E

Dep. I Req. C / E

Dep. I Req. C / E
A couple of students [13:45]: They’re different. Give C / E

Sandy: They’re going to be different. Accept.

So, if you take a ‘one-to-one mass ratio’ in the balanced equation, Give C / E

it will only work if the things are the same size and they have the

same mass. So, somebody go to the periodic table and look up zinc Prep. I

and sulfur please – or read from here if you have ‘eagle eyes.’

Unknown female student: Whoever’s closest. Prep. R

[This takes several seconds. Sandy has to implore someone

to go over and do this. Finally, a female student (FS 4) does this . . .]


Sandy: I want P.T. values for zinc Emb. R


Sandy: Thank you. Emb. I

FS 4: You’re welcome. Emb. R
Sequence 13

133. Sandy [after writing these values on the board]:

So, I chose ‘6.54 grams’ of zinc; how many grams

of sulfur are going to work?

134. MS 1 [14:51]: ‘3.2’

[*It is important that MS 1 has obviously seen the ratio relationship and that Sandy does not ask him to elaborate on how he came up with this value. It is also important that even though he gave the I / P, it was Sandy’s I / P.]

135. Sandy: ‘3.21’ So, if that’s the real ratio that follows the balanced equation, we should get a better reaction.

[**It is really important that Sandy has not only provided the I / P for the students, but provided the prediction of the results of testing based on that I / P.]

H. Conducting a Test II [Begins at 15:04]

Sequence 17

140. Sandy [17:12]: Okay, now this time you should see . . . if

this is the correct ratio – and it’s a true ratio of ‘one atom of zinc to one atom of sulfur,’ this should look more homogeneous than the last one did. The last time, what was true of the color of the mixture –
it was overwhelmingly what color?

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<tr>
<td>144.</td>
<td>Sandy: Grey. Grey – there was twice as much zinc as there was sulfur.</td>
<td>Nuc.</td>
<td>F</td>
<td>Give Confirm.*</td>
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[*She waited until she got the answer she wanted before re-stating the response, which indicates how she uses re-stating to confirm / evaluate answers.]

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<td>147.</td>
<td>Sandy [taking the mixture from S 5]: It’s still overwhelmingly grey . . . all right.</td>
<td>Dep.</td>
<td>R</td>
<td>Accept.</td>
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<tr>
<td>150.</td>
<td>FS 1 [17:47]: Wouldn’t it be more grey?</td>
<td>Dep.</td>
<td>F / I</td>
<td>Ref. Reas.**</td>
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<tr>
<td>151.</td>
<td>FS 3: But there’s still twice as much zinc, why would it be yellow?</td>
<td>Dep.</td>
<td>I</td>
<td>Ref. Reas.**</td>
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[**These have been interpreted as a 2nd and a 3rd refutation (along with line 145) of Sandy’s utterance in line 144.]
152. MS 7: Exactly. 

[*This is a response to FS 1’s comment in line 150.]

153. FS 4: Well, it’s the same amount of zinc . . . 

[**This is a response to – a refutation of – FS 3’s question in line 151.]

154. Sandy: It’s the *same amount* of zinc – half as much sulfur. 

[***This is a follow-up to FS 3’s question in line 151 and FS 4’s response in line 153.]

155. MS 6: I thought it was more yellow last time. 

156. MS 1: So wouldn’t that make it *less* yellow? 

[****This is a questioning of the logic behind Sandy’s statement in line 154.]


158. MS 1: Because there’s *less* sulfur .

159. Sandy: . . . oh yeah. Oh, that’s true.

I. Analyzing the Results II [Begins at 20:10]

*Sequence 19*

168. Sandy: All right. There, how was that one? 

169. [Another round of applause ensues.]

170. Sandy: And some thanks to my lovely assistants.
[Students cheer for them and give a weak round of applause, causing laughter.]

*Sequence 20*

172. Sandy [20:27]: All right. Woo!! So, if you add the amount that gives you the *true* atom ratio – you *look* at the periodic table – and you add them, if you have ‘6.54 grams’ of zinc with ‘3.21 grams’ of sulfur, how many grams of zinc sulfide do we think we make?

173. S 1: ‘9.75’.

174. Sandy: ‘9.75 grams’ [writes this on board]. All right, so all of these values follow the periodic table – so they match. So, if you look to a *tenth* – one tenth of each value from the periodic table, it’s still ‘one-to-one-to-one.’ Okay, a tenth of the value from each thing – same amount by *number of atoms*, different amount by *mass*, but it works out to be the same thing. So this is what you’ve been building towards. You learned how to name the ions, you learned about electron configurations, then you learned about the structure of the periodic table, and then you used the periodic table and the electron configurations to
put the compounds together. And see, it worked, because you knew that
that was ‘zinc sulfide,’ and that this was a synthesis reaction. Okay,
you’ve learned a lot of stuff. Now we’re going to put it to use for us,
using these numbers and figuring out things like this [referring to the
determination of the correct reaction mixture]. The fancy name for
this is stoichiometry. It’s mole math, okay. It’s mole math.

175. Several students in unison: M-o-l-e. Dep. I

[Sounding the name out slowly.]


177. Several students [largely female]: Yeah! Dep. F

178. Sandy: So we can finally take down you’re t-shirts and put up Dep. I

new mole day art.

179. Several students [largely female]: Yeah! Dep. R


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Vitae

Brett Allen Criswell was born in Lewisburg, Pennsylvania. His entire K–12 educational experience was within the Warrior Run High School, from which he graduated as class valedictorian. He was awarded a Paul Douglass scholarship from the state of Pennsylvania for selecting to pursue a degree in science education. Further, he received the Corinne Menk Wehr academic scholarship from Indiana University of Pennsylvania (IUP), where he majored in secondary education with a focus on chemistry. During his undergraduate period at IUP, he received the chemistry department academic achievement award three out of four years. He graduated from IUP summa cum laude.

Following the attainment of his B.S. in chemistry education, Brett was hired by Central Columbia School District near Bloomsburg, Pennsylvania. He taught there between 1988 and 2005, taking a leave of absence and a sabbatical during that period, the first to begin work on his master’s degree and the second to begin work on his doctoral degree. While at Central, Brett was recognized as an educational leader, spearheading an effort to revamp the K–12 science curriculum in order to make it more representative of the spiral model suggested by Bruner and more aligned with the national science reform documents.

In May 2003, Brett completed his M.S. degree in Science Education, awarded by the University of Pittsburgh. The following spring, he began the PhD program at Penn State. He made a full-time commitment to the program following his resignation from Central Columbia in 2006; his PhD degree will be conferred in August of 2009. He has already accepted a tenure-track position at Kennesaw State University outside of Atlanta, Georgia as part of a team committed to making the university one of the top producers of science education majors in the country. He also hopes to be able to continue his interest in classroom discourse while there.