The Role of the Teacher in Supporting Students in Writing Scientific Explanations

Katherine L. McNeill

Boston College

contact info:

Lynch School of Education, Boston College

140 Commonwealth Avenue, Chestnut Hill, MA 02467

Phone: 617-552-4229

Fax: 617-552-1840

kmcneill@bc.edu

Reference as:

McNeill, K. L. (2007, April) *The role of the teacher in supporting students in writing scientific explanations.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Abstract
The role of the teacher is essential for students' successful engagement in scientific inquiry practices. I examined how middle school science teachers supported their students in one particular inquiry practice, the construction of scientific explanations. This study focuses on an eight-week chemistry curriculum that explicitly supports students in constructing scientific explanations about phenomena in which they justify their claims using evidence and reasoning. Participants included six teachers and 568 students. Videotapes and two questionnaires were analyzed from each teacher to develop case studies that characterized the support the teachers provided their students for scientific explanation. Patterns from the case studies suggest that the teachers defined scientific explanations in a variety of ways for their students. These different definitions of scientific explanation influenced the other instructional practices that the teachers engaged in to support their students. There were also differences in the classroom discourse across the teachers in terms of whether the conversation was solely teacher driven or whether the students also took initiative and ownership in the classroom discussion. Teacher differences in instruction around scientific explanation may reflect their beliefs about what counts as scientific explanation and science instruction.

The Role of the Teacher in Supporting Students in Writing Scientific Explanations

Curriculum materials are an important tool to help teachers engage their students in inquiry, particularly educative materials that are specifically designed to promote teacher learning (Davis & Krajcik, 2005). Yet, we cannot assume that the use of these materials is going to look the same in all classrooms. Teachers draw on their own resources and capacities to read, make meaning, evaluate and adapt curriculum materials (Remillard, 2005). Ultimately, classroom practice is influenced by the teachers' understanding of the curriculum, beliefs about what is important, and ideas about the roles of the teacher and students (Ball & Cohen, 1996). The role of the teacher is essential for students' successful engagement in scientific inquiry practices (Crawford, 2000, Reiser et al., 2000).

Yet, there is little research on teacher instructional strategies and the student-teacher interactions that result in successful inquiry learning environments (Crawford, 2000; Flick, 2000; Keys & Bryan, 2001). Recent work in this area has included case studies of between one and four teachers using inquiry-oriented curriculum materials. These studies suggests the importance of teachers helping students make connections between activities and concepts (Puntambekar, Stylianou, & Goldstein, 2007), engaging in practices that are consistent with the inquiry goals in the curriculum (Schneider, Krajcik & Blumenfeld, 2005), modeling how to engage in scientific inquiry practices such as grappling with data (Tabak & Reiser, 1997), and connecting to students' everyday experiences and funds of knowledge (Moje, Collazo, Carillo & Marx, 2001). In this paper, I build off of these and other studies to identify essential teacher instructional practices for supporting students in scientific inquiry during the enactment of a middle school inquiry-oriented chemistry curriculum. Specifically, I am interested in the role of the teacher in supporting students in one particular scientific inquiry practice, scientific explanation or argumentation.

Conceptual Framework

Scientific Explanation

Explanation (Nagel, 1961) and argumentation (Driver, Newton & Osborne, 2000) are often discussed as core practice of scientists. Consequently, if we want students to engage in authentic science learning, they need to engage in these practices to think and act like scientists. Science is not about discovering or memorizing facts; rather it is about constructing arguments and considering and debating multiple explanations for phenomena (Osborne, Erduran, & Simon, 2004). This type of explanation construction occurs within a community of scientists where different explanations are compared, debated and countered with competing explanations. Scientific knowledge is far more complex, tenuous and situated in the scientific community than is often recognized (McGinn & Roth, 1999).

An explanation in science can refer to how or why something happens (Chin & Brown, 2000). Science may be best characterized as the endeavor to explain the natural world (Sandoval, 2005). Scientists try to explain phenomena by determining how or why they occur and the conditions and consequences of the observed event (Nagel, 1961). An argument focuses on justifying or defending a standpoint for an audience (van Eemeren, et al., 1996). An argument is a social activity in which an individual tries to convince others either through talk or writing about the validity or a particular assertion. Scientific argumentation is a logical discourse that uses evidence to construct and defend claims, which differs from everyday argumentation that relies on power and persuasiveness (Duschl et al., 2006). In my work, I combine the goals of explaining and justifying to support students in constructing scientific explanations about phenomena where they justify their claims using appropriate evidence and scientific principles. To support students in writing scientific explanations, my colleagues and I developed an instructional framework for scientific explanation (McNeill, Lizotte, Krajcik & Marx, 2006; Moje, Peek-Brown, Sutherland, Marx, Blumenfeld & Krajcik, 2004). Similar to other science education researchers (Bell & Linn, 2000; Driver, et al., 2000; Erduran, et al. 2004; Sandoval, 2003), we used an adapted version of Toulmin's model of argumentation (1958). We developed the instructional framework in order to reduce the complexity for students (Quintana et al., 2004) and to focus the attention of the learner on the relevant task features (Pea, 2004). The instructional framework breaks down scientific explanation into three components: claim, evidence, and reasoning (McNeill, et al., 2006). The claim is an assertion or conclusion that answers the original question. The evidence is scientific data that supports the claim. The data should be both appropriate and sufficient and can come from a variety of sources including first hand data the students collected themselves or second hand data that they obtain from another resource such as a book or online. The reasoning is a justification that shows why the data count as evidence to support the claim. The reasoning should include the scientific principles the student applied to the situation and the logic behind that application.

Teacher Instructional Practices for Scientific Explanation

Scientific argumentation needs to be explicitly taught by the teacher through appropriate modeling and other support in order to alter the typical classroom discourse (Simon, Erduran, & Osborne, 2006). Yet there has been little research on the role of the teacher in supporting students in scientific explanation or argument. Some of the work that has been done stresses the importance of the teacher and curriculum materials sharing the same learning goal for explanation in order for the two supports to work synergistically (Tabak, 2004). Simon, Erduran and Osborne (2006) have identified a number of different types of teacher talk, such as knowing the meaning of argument and evaluating arguments, that may promote students' ability to engage in argumentation. They also found that teacher differences in their emphasis on different components of argument might be a result of their varied understandings of what counts as an argument suggesting that teacher beliefs also play an important role (Erduran, Simon & Osborne, 2004).

In previous work with my colleague (McNeill & Krajcik, in press a), we investigated the influence of four different teacher instructional practices on students learning of scientific explanations: defining scientific explanation, making the rationale of scientific explanation explicit, modeling scientific explanation, and connecting scientific explanation to everyday explanation. We analyzed the videotape of one lesson from thirteen teachers to investigate what instructional practices teachers used to introduce scientific explanations and how those instructional practices influenced student learning. We found that students' ability to write scientific explanations improved the greatest when teachers provided a rationale for engaging in scientific explanation and explicitly and appropriately defined the different components of the scientific explanation framework (i.e. claim, evidence, and reasoning). A limitation of this previous study was that it was not able to explore the teacher instructional practices in depth or over time. Rather the study only provided a quick snapshot of what occurred in the science classrooms.

In this study, I explore in more depth the four instructional practices investigated in the previous research (McNeill & Krajcik, in press a). We included defining scientific explanations, because diverse learners may not be familiar with the scientific inquiry practices (Fradd & Lee, 1999) and making scientific thinking strategies explicit can support students in successfully engaging in these practices (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999). Making the rationale of scientific explanation explicit can help students understand the logic behind the inquiry practice (Kuhn, D., Black, Keselman, & Kaplan, 2000). Having a teacher model a scientific inquiry practice can support students when they engage in this same practice independently (Tabak & Reiser, 1997). Finally connecting scientific discourse and everyday discourse can help students engage in these scientific inquiry practices (Moje et al., 2001). The codes for these instructional practices were revised to capture a more in depth picture of the support provided by the teacher and used to analyze multiple lessons during the unit. A more complete discussion of the rationale behind the importance of these four instructional practices can be found in McNeill & Krajcik (in press a).

In addition, three more instructional practices were examined in this study: providing feedback to students, connecting to students' prior understandings or experiences, and discussing the science content accurate and completely. Providing feedback was added, because feedback that focuses on what needs to be done with the specific goal of helping students learn (compared to just being a rating of achievement) can improve student performance (Black, 2003). Connecting to students' prior knowledge was included because when children enter a classroom, they have prior knowledge about science phenomena, even if they have had no formal instruction on the material (Bransford et al., 2000; Driver, Guesne & Tiberghien, 1985). Science instruction needs to activate and build upon this prior knowledge. Finally, the last instructional practice focused on the science content was included because of the important relationship between students' understanding of the content and success at engaging in scientific inquiry practices (Metz, 2000; McNeill et al., 2006). Even if a teacher engaged in a variety of instructional practices to support students in scientific explanation, if the teacher's discussion of the science content was inaccurate or incomplete, there would not be large learning gains in terms of students' ability to write scientific explanations. In this study, I develop a rich picture of how teachers' support students in scientific explanation across an eight-week curriculum unit as well as compare how that support aligns with the original goals of the curriculum.

Method

Instructional Context

This study focuses on an eight-week standards-based chemistry curriculum, *How can I make new stuff from old stuff?* (*Stuff*) (McNeill, Harris, Heitzman, Lizotte, Sutherland & Krajcik, 2004), which is part of the Investigating and Questioning our World through Science and Technology (IQWST) curriculum materials. We developed the materials using a learning-goals-driven design model (Krajcik, McNeill & Reiser, in review) that emphasizes the alignment of the materials with national standards (AAAS, 1993; NRC, 1996).

Stuff engages students in the study of substances and properties, the nature of chemical reactions, and the conservation of matter. In the *Stuff* unit, we contextualized the science concepts and scientific inquiry practices in real world experience by focusing on making soap from fat or lard and sodium hydroxide (making new stuff from old stuff). Students complete a number of investigations where they revisit soap and fat throughout the unit. These cycles help students delve deeper into the key learning goals including both target science content and the scientific inquiry practices such as the analysis of data and construction of scientific explanations.

To introduce students to scientific explanations in the *Stuff* unit, we developed a focal lesson that occurs about two weeks into the unit. The lesson calls for the teacher to introduce the scientific explanation framework and engage in a variety of instructional practices. After the focal lesson, there are opportunities in the curriculum for students to write eleven more scientific explanations. Table 1 describes all of the activities in the unit where students could write scientific explanations. Students record the results of their investigations and scientific explanations on student investigation sheets that provided students with the written curricular scaffolds. Based on the results of a previous study conducted in the context of the *Stuff* unit (McNeill et al., 2006), the curricular scaffolds fade or provide less support over time, because we found that fading resulted in students writing stronger explanations over time. The last three opportunities for students to write scientific explanations do not include curricular scaffolds. A more detailed discussion of the curricular scaffolds used in this study can be found in other work (see McNeill & Krajcik, 2007).

Table 1: Explanations Constructed During the Unit

Content Area	Learning Task
Substance & Property	Activity 6.1: Students determine if soap and fat are the same or different substance based on their previous investigations where they collected data on a variety of properties.
Substance & Property	Reader 6.1: Students are provided with data on two different stones and determine whether they are the same substance.
Substance & Property	Activity 7.1: Students mix together a number of substances and have to determine if a new substance is formed.
Chemical Reaction	Reader 7.1: Students are provided with the properties for the substances they mixed in class and have to determine if a chemical reaction occurred.
Chemical Reaction	Activity 8.2: Students investigate what happens when a penny and vinegar are combined and determine whether a chemical reaction occurred.
Chemical Reaction	Activity 10.1: Students investigate whether boiling is a chemical reaction.
Chemical Reaction	Activity 10.2: Students investigate whether combining powdered drink mix and water is a chemical reaction.
Conservation of Mass	Optional Activity 13A: Students combine different substances in a chemical reaction to form "gloop" and have to determine whether mass changes.
Conservation of Mass	Activity 13.1: Students react Alka Seltzer and water in an open container and determine whether the mass changes.
Conservation of Mass	Activity 13.2: Students react Alka Seltzer and water in a closed container and determine whether the mass changes.
Conservation of Mass	Reader 13.2: Students are provided with the mass of reactants and products before and after a chemical reaction and determine whether the mass changes.
Substance	Activity 15.1: Students collect data to determine whether they formed a new substance when they mixed fat and sodium hydroxide solution.
Better Soap	Optional Activity 16.A: Students collect data to determine whether their soap performs better than store bought soap.

The curriculum materials were also designed to be educative. By educative curriculum materials, I mean teacher materials that are specifically designed to promote teacher learning (Ball & Cohen, 1996; Davis & Krajcik, 2005). In order for curriculum materials to be educative they need to make the rationales behind curriculum developers' decisions visible to teachers in order to help teachers develop flexible knowledge that they can apply to new situations (Davis & Krajcik, 2005). We included a number of educative features in the curriculum materials around scientific explanation. These educative features include discussing why scientific explanation is important, what scientific explanation is, providing general strategies for supporting students with explanations as well as concrete examples, and providing both strong and weak examples of students' explanations.

Participants

Participants in this study included six teachers and 568 seventh grade students from six middle schools in the Mid-west. Five of the teachers (Ms. Marshall, Mr. Kaplan, Ms. Hill, Ms. Foster, and Ms. Kittle) taught in the same large urban area. The majority of students for these teachers were African American and from lower income families. The last teacher, Ms. Nelson, taught in an independent middle school in a large college town. The majority of the students in the independent school were Caucasian and from middle to upper-middle income families.

The context that Ms. Nelson taught in and the student population was distinctly different compared to the other five teachers. Because of these differences, if there are differences in enactment and learning in Ms. Nelson's class, I will not be able to determine if those differences are a result of the context, the student population or the teacher practices that Ms. Nelson uses. Nonetheless, I decided to keep Ms. Nelson in the study as a contrasting case to see if there are marked differences in her enactment and students' learning. In purposive sampling of cases, the atypical case often offers the researcher a greater opportunity to learn about the phenomenon of interest (Stake, 2000).

The teachers in this study had a range of backgrounds and previous experiences. The primary criterion used for selection was opportunity to learn from these cases about the research question of interest (Stake, 2000). Since I was interested in naturally occurring contrasts (Shadish, et al., 2002) in the teachers' instructional practices, I purposively selected teachers with a variety of experiences to participate in this study. Including variation in my selection of cases increased my chances of seeing variation in their actual classroom practice. I also asked these six teachers to participate, because they were accessible and willing to provide all of the data necessary for the study. Table 2 provides a brief description of the teachers' backgrounds.

Table 2: Teachers' Backgrounds and Experiences

Teacher	Race/ Ethnicity	Years Teaching	Years Teaching Science	# Years with hi-ce Curricula	# Times taught Stuff	Highest Degree
Ms. Kittle	African-American	7	7	3	1	MA
Ms. Marshall	Caucasian	4	4	2	0	BS
Ms. Hill	African-American	27	24	1	0	MA
Mr. Kaplan	Caucasian	4	4	0	0	MEd
Ms. Foster	African-American	7	7	3	3	BS
Ms. Nelson	Caucasian	13	13	2	2	MA

The teachers ranged in teaching experience from four years to twenty-seven years with the majority of all of their time teaching focused on science. The research group in which I completed this study, the center for highly interactive classrooms, curricular, and computing in education (hi-ce), has been working with middle school teachers in this large urban area for a number of years. Consequently, all of the teachers except one, Mr. Kaplan, had previously enacted one of the reform-based curricula developed by hi-ce. Specifically, in terms of the *Stuff* unit, three of the teachers had used the unit previously while three of the teachers had never used it before. Consequently, the teachers brought a range of experiences and backgrounds to the enactment of the unit.

The five teachers who taught in the large urban area also had the opportunity to attend professional development specifically designed around the reform-based curriculum. The professional development included a one-week summer workshop and monthly Saturday workshops focused around issues related to the enactment of the curriculum materials. Although the workshops are developed in partnership with hi-ce researchers, the district assumed primary responsibility for the workshops in 2003. Each workshop is planned and conducted by "lead teachers" who have successfully used the curriculum materials in their classroom in the past (See Fogleman, Fishman & Krajcik, 2006 for more detail). As I will discuss later in the case studies, the professional development workshops appeared to impact some of the teachers' enactment of the curriculum specifically around scientific explanation.

Data Sources

I collected data from multiple sources to measure teacher instructional practices and student achievement and learning in terms of scientific explanation. The data sources included identical student pre and posttests, classroom videotapes of three lessons, teacher explanation questionnaires, and teacher curriculum questionnaires.

Pre and posttest. All students completed identical pre and posttest measures that included 15 multiple-choice items and 4 open-ended responses. The multiple-choice items serve as a measure of students' understanding of the three key content learning goals independent of students' ability to use that understanding in the construction of scientific explanations. The open-ended responses included three scientific explanations one for each of the three main content goals: substance and properties, chemical reactions, and conservation of mass.

Classroom videotape. The same three lessons were videotaped for each teacher and then coded the lessons for instructional practices. The three videotaped lessons were Lesson 6, Lesson 8, and Lesson 13 (see Table 1). I selected these three lessons for a variety of reasons. First, each activity focused on a different content area: substance and property, chemical reaction and conservation of mass. Furthermore, all three activities ask students to analyze a variety of pieces of data, which could result in conversations about what counts as appropriate and enough data.

Specifically, I selected Activity 6.1, because this is the focal lesson on scientific explanation. As I described under the instructional context, this is the first time during the unit that the class discusses explanations and students construct explanations. I selected Activity 8.2, because this is the first activity students complete where they are asked whether a chemical reaction occurs. Both activities 6.1 and 8,2 covered two class periods and I videotaped these lessons for all six teachers.

For Lesson 13, I planned to videotape Activity 13.2 where students react Alka Seltzer and water in a closed system. Unfortunately, a number of issues arose around the taping of this lesson. For one teacher (Ms. Kittle), videotape was not obtained because of communication difficulties. For the remaining five teachers one day of videotape for Lesson 13 was obtained though the specifics of the taping varied. For two teachers (Mr. Kaplan and Ms. Hill), Activity 13.2 was videotaped (Alka seltzer in a closed system), which was the original intent. One teacher (Ms. Foster) Activity 13.1 was taped (Alka seltzer in an open system), because she never completed 13.2. Another teacher (Ms. Marshall) combined 13.1 and 13.2 into one class period, which was taped. For the last teacher (Ms. Nelson) there were technical problems with the videotapes for both 13.1 and 13.2 so Activity 13A was analyzed, which is an optional activity. I considered not analyzing lesson 13, because of the variation in videotapes across teachers, but did not want to discard available data. Instead, I considered these differences in activities when reducing the data and characterizing the instructional practices of each teacher across the unit.

Teacher explanation questionnaire. As I mentioned previously, five of the six teachers previously enacted reform-based curriculum designed by hi-ce and all six attended hi-ce professional development where scientific explanations were discussed as an important learning goal. Since the teachers did not begin the *Stuff* until January of the 2004-2005 school year, all of them had already introduced the concept of scientific explanations to their students earlier in the school year. In order to obtain a measure of what had happened in their classrooms prior to *Stuff*, they filled out a questionnaire about their practices and their students' difficulties around explanation.

Teacher curriculum questionnaire. During the *Stuff* unit, three out of the sixteen lessons were videotaped. From previous enactments of the unit, we found that teachers adapt the unit by skipping, modifying, or adding different activities in the unit (Fogleman & McNeill, 2005). In order to have a base level understanding of what aspects of the unit each teacher did and did not complete, they completed a questionnaire as they enacted the unit. Each lesson had a check off page where the teacher marked what they did and did not complete, their comfort level, their students' comfort level and comments on any modifications they made.

Data Analysis

In this section, I discuss the analysis for each individual data source as well as how I combined the data sources to create the case studies.

Pre and posttest. Multiple-choice responses were scored and tallied for a maximum possible score of 15. In order to check the reliability of the multiple-choice items to determine whether the items were internally consistent and measuring a single latent variable, I calculated Cronbach's alpha. For students' scores on the posttest multiple-choice items, Cronbach's alpha is 0.777 suggesting that the items represent a valid measure of students' conceptual knowledge.

The three explanation items were scored using rubrics. With my colleagues (Harris, McNeill, Lizotte, Marx & Krajcik, 2006, McNeill et al., 2006, McNeill & Krajcik, in press) I developed specific rubrics with tailored scoring levels for each of the three scientific explanations. Sandoval and Millwood (2005) argue for the importance of assessing the conceptual adequacy of students' arguments along with structural analyses. Our method of adapting a basic explanation rubric to a specific content area and tasks combines both structure and content. Explanations that receive the highest score include accurate science content and the appropriate explanation structure to support the claim. In other work (McNeill et al., 2006, McNeill & Krajcik, in press b), we provide examples of the rubrics, samples of student responses and describe in detail the coding procedure.

The students' written scientific explanations on the pre and posttests for all three explanation items were scored by one rater. I randomly sampled 20% of these open-ended test items and scored them myself, as a second independent rater. For the three written explanations the estimates of inter-rater reliability were calculated by percent agreements from the sample of 20% where there was overlap between two raters. The inter-rater agreement was 98% for claim, 94% for evidence, and 98% for reasoning across the three explanation items. As a second check of the reliability of the explanation scores as a valid measure, I calculated Cronbach's alpha. For students' scores on the posttest scientific explanations, Cronbach's alpha is 0.809 suggesting that the explanation items represent a cohesive construct.

Classroom video. Videotape from each teacher was analyzed across three lessons during the *Stuff* unit. I developed a coding scheme for the videotapes from both my theoretical framework and an iterative analysis of the data (Miles & Huberman, 1994). Table 3 provides a summary of the coding scheme for the seven instructional practices discussed previously in the theoretical framework.

For the analysis of the videos, a more detailed version of this coding scheme was used which characterized the quality of each instructional strategy, provided specific criteria, and examples of the criteria (McNeill, 2006). All lessons were scored by one rater for a total of 17 lessons and 29 videotapes. I then randomly sampled two teachers for each lesson, which consisted of 10 videotapes or 34% of the total tapes. A second independent rater scored these videotapes. Inter-rater reliability was calculated by percent agreement. Inter-rater reliability was 88%. All disagreements in coding were resolved through discussion.

Table 3: Coding Scheme for Teacher Instructional Practices

Code	Description
1. Defining scientific explanation	Does the teacher explicitly discuss what a scientific explanation is? How does the teacher define scientific explanation and the components?
2. Modeling and critiquing scientific explanation	Does the teacher model how to construct a scientific explanation either through writing or through talking? Does the teacher identify the different components of explanation as he or she models the explanation? Is the modeling of scientific explanation accurate and appropriate? Does the teacher identify the strengths and weaknesses of the explanations?
3. Making the rationale behind scientific explanation explicit	Does the class explicitly discuss the rationale behind engaging in scientific explanation either in terms of explanation as a goal of science or the importance of persuasive discourse?
4. Connecting scientific explanations to everyday explanations	Does the teacher provide examples of everyday explanations? Does the teacher discuss how constructing explanations in science is similar and different to constructing explanations in everyday life?
5. Providing feedback to students	Does the teacher provide feedback on explanations that the students provide during discussion? Is the feedback accurate and appropriate? Does the teacher provide written feedback to the students on their explanations? Is the feedback accurate and appropriate?
6. Taking into account students' prior understandings or experiences	Does the teacher ask students questions about their prior understandings of scientific explanation? Does the teacher connect the lesson to previous lessons when students have constructed explanations or completed similar inquiry practices like using evidence to make claims?
7. Accuracy and completeness of science content	Does the teacher discuss the key science principles for the explanation? Is the discussion accurate? Is the discussion complete?

Teacher case studies. I used the data from both the videotapes of classroom practice and the two teacher questionnaires to develop case studies of the enactments for the six teachers. For each case, I used the data sources to develop a description of the complexities (Stake, 2000) within the classroom around the teacher supporting scientific explanations. Analyzing the videotapes resulted in a great volume of data all of which cannot be reported. When creating the detailed case studies, my goal was to create a narrative that accurately characterized and represented the most important features of each case to tell the story of what support each teacher provided their students for scientific explanation (Stake, 2000). After creating each detailed case study, the research assistant trained to code the videotapes read and evaluated each case study. She read them keeping in mind whether the case study was consistent with the one lesson she coded for each teacher as well as in terms of the codes for the seven instructional practices. Overall, she found the case studies consistent with her experiences. The few discrepancies she found and areas she felt were unclear, we discussed and revised accordingly. The finalized detailed case studies ranged in length from thirteen to twenty pages for each teacher.

There is a tension in creating case studies in terms of how much information to present to the reader. Less information is always present than was actually learned during the study. The researcher is guided in presenting the case by multiple factors including the importance of the information, representing the case comprehensibly, the goal of the study, and a consideration of the reader (Stake, 2000). Consequently, I chose to include less detail in the shortened case studies presented in this paper and focus on those aspects of each teacher's practice that characterized his or her classroom as well as distinguished each teacher from the other teachers. Again, after reducing the data to create these shortened case studies, the research assistant read them to check that they were consistent with the detailed case studies and the original coding of the videotapes and any discrepancies were revised. A more in depth description of this process and the detailed case studies can be found in other work (McNeill, 2006).

Results

The results from this study address three specific research questions:

1. What instructional practices do teachers engage in during the unit to support students in writing scientific explanations?
2. Does student learning of scientific explanation vary by teacher?
3. Are these instructional practices related to any differential learning of scientific explanation?

I begin by describing the teachers' enactment of the curriculum and what instructional practices teachers engaged in during the *Stuff* unit around scientific explanation. I discuss whether there was differential learning of scientific explanation by teacher. Finally, I examine whether there appears to be any relationships between the enactments and instructional practices teachers engaged in and their students' learning of scientific explanations.

Enactment of the Curriculum

I used the data from both the videotapes of classroom practice and the two teacher questionnaires to develop case studies of the enactments for the six teachers. I was interested in obtaining a general description of the teachers' completion of the unit and a more detailed image of what instructional practices they used in their classrooms to support students in scientific explanation. First, in terms of the completion of the unit the teachers' enactments varied. Table 4 provides a summary of their completion of the unit. For the number of lessons completed, there is variation across the six teachers. The level of completion ranged from 10 to all 16 lessons. All six teachers did report completing lessons that addressed all three content learning goals (i.e. substance and properties, chemical reactions and conservation of mass) and the three focal lessons for this study (i.e. Lessons 6, 8, and 13).

Table 4: Teachers' Enactment of the Stuff Unit

	Number of Lessons Completed	Skipped Lessons	Adaptations of Activities in 3 focal lessons	Number of Curricular Scaffolds
Mr. Kaplan	15 of 16	Lesson 16	Close match	6 of 9
Ms. Marshall	10 of 16	Skipped Lessons 5, 7, 11, 14, 15, & 16	Significant adaptations	0 of 9
Ms. Hill	15 of 16	Lesson 16	Close match	8 of 9
Ms. Foster	11 of 16	Skipped Lessons 5, 10, 11, 15, & 16	Slight adaptations (Lesson 13)	4 of 9
Ms. Kittle	12 of 16	Skipped Lessons 10, 12, 15, and 16.	Slight adaptations (Lesson 13)	4 or 5 of 9
Ms. Nelson	16 of 16	none	Close match	9 of 9

The column in Table 4 that describes adaptations to the activities for the three focal lessons is a general measure based on the videotapes of teachers' enactments. I was interested in whether the teachers had the students complete the activities in the three lessons and write their explanations on the student investigation sheets. Three of the teachers (Mr. Kaplan, Ms. Hill, and Ms. Nelson) had the students complete all of the activities for the three lessons and write their responses on the corresponding student investigation sheet. Two of the teachers (Ms. Foster and Ms. Kittle) closely matched the curriculum, except they did not have students write their explanations on their investigation sheets for part of Lesson 13. Ms. Foster reported in her questionnaire that she skipped the second activity in Lesson 13 in which students react Alka Seltzer in an open system. Consequently, it is not surprising that none of her students wrote explanations for this activity. Ms. Kittle reported that she did complete Lesson 13, yet in examining her student books there was some variation across her classes. Two of her classes wrote scientific explanations for the first activity where they reacted Alka Seltzer in a closed system, while students in the other three classes did not write scientific explanations. None of her students in any of her classes wrote scientific explanations for the second activity in Lesson 13 where they reacted Alka Seltzer in an open system. Unfortunately, there is not videotape for Ms. Kittle for this lesson to know how she modified Lesson 13.

Finally, Ms. Marshall made the most extensive adaptations to the unit. Although she had students complete the activities associated with the three focal lessons, she never had the students write their explanations in their investigation books. For Lesson 6, she had students write their explanations in PowerPoint on laptops. For Lesson 8, she had students create "foldables" and describe the chemical reaction in the foldables. By foldables, Ms. Marshall meant that students would fold a piece of paper to create different squares in which they wrote text and drew pictures about the chemical reaction they completed in class. Finally, for Lesson 13 she gave the students a separate data table to record their data and describe what happened.

For each teacher, I also examined the student investigation books to determine how many scientific explanations students typically wrote in their classes. There was some variation within each teacher probably based in part on student absenteeism. The number in Table 4 represents the number of explanations written by the majority of students for each teacher. The number of explanations students completed in their investigation book varied by teacher from zero to all nine.

Case studies of teacher support for scientific explanation

In developing the case studies, I used both the teacher questionnaires and the videotapes of their classroom enactments. Table 5 provides a summary of the frequency and the quality of the six teachers' use of the seven instructional practices during their enactment of the *Stuff* unit. In the shortened case studies below, I focus on two aspects of the teachers' enactments that characterized their enactments and distinguished them from each other: the way teachers defined scientific explanation and their classroom discourse. The way the teachers defined scientific explanation appeared to impact how they engaged in other instructional practices such as modeling and providing feedback. The case studies also include at least one example of the different instructional practices for scientific explanation to illustrate how their definitions of scientific explanation aligned with the other support they provided students in their classroom instruction.

Mr. Kaplan. In all three focal lessons, Mr. Kaplan included scientific explanations as a key learning goal in the lesson and provided students with multiple supports to help them write scientific explanations. Mr. Kaplan's definition of scientific explanation closely aligned with the intent and the instructional framework for scientific explanation provided in the curriculum materials. In all three lessons, he discussed how a scientific explanation consisted of three components: claim, evidence, and reasoning. He particularly stressed the idea of reasoning and often discussed the importance of including a scientific principle that justified why the evidence supported the claim. For example, in lesson 13 he said, "Again, the reasoning has to link the evidence to the claim. In other words, you have to ask yourself why is it this way? How is it this way?" Then a couple of minutes later he said, "In the reasoning, you have to answer why. What scientific principle - what scientific principle explains why?" When he talked about the rationale behind scientific explanation, he focused on the persuasive goal which created a need for the evidence and reasoning components. He talked about wanting to "convince someone of your claim" and how "if you really really want something you are going to argue for it."

During every lesson, Mr. Kaplan assessed and provided feedback to students both individually and as a whole class that aligned closely with his definition of scientific explanation. His feedback tended to focus on the different components of scientific explanation and how students could improve those components. For example, in Lesson 8 after he had one group of students share their explanation Mr. Kaplan focused the conversation around their reasoning they included in their written explanation. He said, "How could I complete this to make it a more complete reasoning? How can I link the evidence to the claim with the one principle relating to properties that we talked about? You have to think chemical reaction, properties, new substances? How can I kind of put all of those things together to hit this home?"

Overall, scientific explanation was an important learning goal in Mr. Kaplan's class and he provided his students with multiple forms of instructional support. Mr. Kaplan engaged in all seven instructional practices during at least one of the lessons. Furthermore, his support for scientific explanation was congruent with the learning goals of the *Stuff* unit.

Table 5: Frequency and Quality of Instructional Practices

Instructional Practices	Mr. Kaplan	Ms. Marshall	Ms. Foster	Ms. Kittle (No Lesson 13)	Ms. Hill	Ms. Nelson
Defining scientific explanation[1]	All 3 lessons C & E vague. R explicit	Lesson 6 Modified – C, E, definition, therefore	All 3 lessons Modified – C, E, definition, conclusion	Both Lessons C explicit. E vague. R modified	All 3 lessons E vague. C & R mentioned	All 3 lessons C, E, R explicit
Modeling and critiquing[1]	All 3 lessons – 10 examples C, E, & R correct & explicit	Lesson 6 – 1 example C & E correct R modified	Lesson 6 & 8 – 5 examples C & E correct. R modified	Both Lessons – 5 examples C, E, & R correct & explicit	Lesson 8 – 2 examples E correct & vague	Lesson 6 & 13 – 5 examples C, E, & R correct, vague & explicit
Making the rationale explicit	Lesson 6 Persuasive discourse	Never	Never	Lesson 6 Persuasive discourse	Never	Lesson 6 Science as explanatory
Connecting to everyday explanations	Lesson 6 – 4 examples Correct & explicit	Never	Never	Never	Never	Lesson 6 – 2 examples Correct & explicit
Providing feedback to students[2]	All 3 lessons I – 3 lessons, often, explicit F - 3 lessons, often, explicit W - none	Lesson 6 I – vague, rare F – none W - none	All 3 lessons I – 3 lessons, often, explicit, modified F – none W - none	Both Lessons I – both lessons, rare, varied F – both lessons, unclear W - none	All 3 lessons I – 3 lessons, varied, explicit F – 1 lesson, often, explicit W – 1 lesson brief	Lesson 6 & 13 I – 2 lessons, rare, but explicit F – none W – all lessons & explicit
Students' prior understandings or experiences	Lesson 6 Teacher connects	Never	Lesson 8 Teacher connects	Never	Lesson 6 Brief reference	Lesson 6 & 8 Connect - students give definitions
Accuracy and completeness of science content	All 3 lessons Accurate, complete & frequent	Lesson 8 and 13 Accurate, but completeness & frequency varied	All 3 lessons Accurate, but completeness & frequency varied	Both Lessons Accurate, complete & frequent	All 3 lessons Accurate, but completeness & frequency varied	All 3 lessons Accurate, complete & frequent

[1] "C" refers to claim. "E" refers to evidence. "R" refers to reasoning.
[2] "I" refers to providing individual feedback. "F" refers to full class discussions. "W" refers to written feedback.

Ms. Marshall. Scientific explanation did not appear to be a major focus of Ms. Marshall's class during the *Stuff* unit. Ms. Marshall only discussed scientific explanations during one of the three focal lessons, lesson 6. Instead of using the language in the curriculum materials of claim, evidence and reasoning, Ms. Marshall used a different definition of scientific explanations that originated from professional development workshops. The teachers in the urban area had the opportunity to attend a monthly professional development workshop specifically designed around the reform-based middle school science curriculum materials (see Fogleman et al., 2006 for more detail). During the professional development workshops, the teachers discussed a different definition of scientific explanation where they talked about reasoning as consisting of a "definition" and a "therefore" statement. For example, at the October 2004 professional development meeting in the urban area, the teacher leading the 7th grade workshop defined scientific explanation in the following manner, "These are the main parts: a claim, a definition, two pieces of evidence, your reasoning statement which some people - you know - you could use this as your definition, and then your 'therefore because'." When Ms. Marshall discussed scientific explanations with her class, she defined explanations as consisting of four components: claim, definition, evidence and therefore.

During Lesson 6, instead of having students write their scientific explanations in their investigation books, Ms. Marshall chose to have students write their explanations on laptops using PowerPoint. She projected a graphic organizer in PowerPoint for her students to copy that consisted of four boxes labeled "Claim", "Evidence 1", "Evidence 2" and "reasoning Therefore" and one circle labeled "Definition." As she discussed the PowerPoint graphic organizer, she provided vague definitions of the components in the graphic organizer and provided students with examples. Although Ms. Marshall said the word "reasoning" once when talking about the graphic organizer, she never discussed what she meant by reasoning. In her graphic organizer, she wrote "Therefore" underneath reasoning, which was the only clarification she provided. She did frequently discuss students' "definition" and "therefore" statements with the class. In talking about the "definition" with the class, she said to the class "what word from my claim should I define?" Students said to define different words including "substance", "lard", and "soap." Ms. Marshall accepted any of these words as appropriate to define. For her example of a definition, Ms. Marshall copied and pasted a definition of substances from the Internet, "A substance can be defined as that which has mass and occupies space. 'An atom is the smallest indivisible unit of matter'." This statement did not provide any reasoning for why Ms. Marshall used solubility as evidence that the soap and lard are different substances. When Ms. Marshall asked the class for a "therefore" statement, one student said, "Therefore, soap and fat are not made of the same substance." Ms. Marshall responded, "because – refer back to your evidence." As this example illustrates, for the "therefore" statement, Ms. Marshall asked her students to repeat the claim and evidence.

Ms. Marshall's discussion of definition and therefore are different than the definition of reasoning in the curriculum materials. The idea that students are defining a word differs from the curriculum materials that suggest that the reasoning articulate a scientific principle that the students used to make their claim and select their data to support their claim. For example, in this lesson the reasoning should talk about how different substances have different properties, such as melting point and solubility, which can be used to distinguish substances from each other. By just discussing a definition and then discussing the therefore as repeating the claim and evidence, she did not include the idea that the reasoning is really providing the logic or justification for why that evidence supports the claim.

Overall, Ms. Marshall only had her students write scientific explanations during Lesson 6, used a different definition of scientific explanation, and provided limited instructional support for scientific explanation. The support that she provided her students did not align with the scientific explanation learning goal of the *Stuff* unit.

Ms. Foster. In Ms. Foster's classroom, scientific explanation was an important learning goal that she frequently emphasized and supported, but similar to Ms. Marshall she used a different definition of scientific explanation than the one in the curriculum materials. Ms. Foster also attended the professional development in the urban area, during which they discussed reasoning as both a definition and therefore statement. Ms. Foster combined that definition of explanation with her own emphasis on conclusions to come up with a modified definition of scientific explanation. Before the *Stuff* unit, she defined scientific explanation as claim, definition, evidence and conclusion or "CDEC" and she continued to connect to and build off of that definition during the unit. The first time the students wrote scientific explanations during the unit she said to her students, "Scientific explanation. So we are going to be good scientists and we are going to use what? (*points to a figure on the wall)* Claim, definition, evidence, conclusion." In the front of the room above the blackboard, Ms. Foster had large cut out letters of "CDEC." Next to the appropriate letter it said: claim, definition, evidence, and conclusion.

Although she frequently talked about CDEC, she did not explicitly define what those components meant. She only vaguely defined claim and evidence. In terms of the definition, Ms. Foster talked about how the students should choose what to define based on "what is it that someone younger than you would not understand. And assume if they would not understand it no one would." Consequently, the goal of the definition was not to provide a logical justification for the claim. For the conclusion, she described this to students as "Just restate the evidence and then you restate your claim. You got your conclusion." She talked about the conclusion as this repetition of the claim and evidence.

In Lesson 8, Ms. Foster used an overhead with examples of scientific explanations to model them for her students. When Ms. Foster evaluated the explanations with her class, she had them critique the explanations in terms of claim, evidence, and conclusion. She told them that they were not going to evaluate them for the definition, because, "We ask for a definition. If you have noticed in our manual, in our book, they do not always ask us to do a definition. But I ask you to do one. So we are not going to penalize them if they do not have a definition, because this is coming from your manual and they did not ask for a definition. I just ask for a definition." Here Ms. Foster is making a distinction between her goals and the goals of the curriculum material. The other instructional practices she provided during the unit also focused on this CDEC learning goal. For example in Lesson 8, in providing students feedback on their explanations, she told one student, "Good that is the first part. That is the C and D. Now give me my E. Where is my evidence? …Give me my evidence. Give me specifics. Give me before and after. Tell me something about before and tell me something about after."

Overall, Ms. Foster prioritized her definition of scientific explanation, CDEC, over the definition of the curriculum materials. She explicitly pointed out the difference to her students and emphasized that she wanted them to follow her requirements not the curriculum materials. Unlike Ms. Marshall, she did however provide students with support to help them with her definition of scientific explanations, CDEC. CDEC was an important learning goal in her classroom and Ms. Foster engaged in a number of strategies to support students in their writing.

Ms. Kittle. In Ms. Kittle's classroom, scientific explanation was a key learning goal and Ms. Kittle supported her students in writing explanations with a variety of instructional practices.

When Ms. Kittle defined scientific explanation during the unit, she used the same language as the *Stuff* unit and discussed how it consisted of claim, evidence and reasoning. Her definition of claim was explicit and appropriate and her definition of evidence was vague and appropriate, but she provided a modified definition of reasoning.

Similar to Ms. Marshall and Ms. Foster, Ms. Kittle attended the professional development in the urban area where they talked about the reasoning consisting of a therefore statement and definition. Before the *Stuff* unit, she defined the reasoning as a "definition" for her students. On her wall in her classroom, Ms. Kittle had a diagram about scientific explanation. Underneath scientific explanation it said: "Claim – the response to the question (answer). Reasoning – define the scientific principle. Evidence – supports your claim (proof). Therefore – restate your claim." During the *Stuff* unit, she tried to help her students refine their understanding of reasoning to move beyond a definition and match more closely with the goals in the curriculum materials. For example, she told her students "You can no longer tell me a definition of a word. You have to tell me how the definition relates to your claim and your evidence." Her new description of reasoning still differs from the *Stuff* unit, which suggests that the reasoning articulate a scientific principle that the students use to make their claim and select their data to support their claim. Yet she did try to align more closely with the definition of reasoning in the curriculum materials in that she was trying to get her students to apply the definition of a science principle.

Ms. Kittle modeled how to construct a scientific explanation and provided students with feedback. Often her use of these two strategies focused on helping students understand this new concept of reasoning. For example, in Lesson 8, she had a number of students share their explanations with the class and she provided them with feedback often focusing on their reasoning. After one of the students read his explanation, Ms. Kittle said to the class, "What is missing from his reasoning?...The connection to the claim. So make sure you remember that connection to the claim and to the evidence. So that it makes sense."

Overall, scientific explanation was clearly an important learning goal in Ms. Kittle's classroom. During the unit, she tried to help her students understand a new definition or framework for scientific explanation that aligned more closely with the curriculum materials.

Ms. Hill. Scientific explanation was also an important learning goal in Ms. Hill's classroom. In all three lessons, she defined scientific explanation in a manner consistent with the curriculum materials. For example, in Lesson 8 she said, "Three parts again – claim, evidence, and reasoning." She also had a diagram on her wall that said "scientific explanation" and included underneath the three components "claim", "evidence" and "reasoning."

When discussing reasoning in class, a couple of times the idea of including a "definition" in students' scientific explanation occurred. Although this idea arose in Ms. Hill's classroom, her definition of explanation was still consistent with the *Stuff* unit, because of her focus on the logic of the scientific explanation. For example, in Lesson 13 students wrote an explanation about whether mass stayed the same or changed when Alka-Seltzer reacted in water. One student asked Ms. Hill if for her definition she should define mass. Ms. Hill responded, "I don't think so. Because is that - is that all you are doing? That is a measure of a material or what something is made up of. Is that really crucial to that? To someone's understanding? No. Ok. I think a clue would be on reader 13.1. Open and closed system." Instead of defining mass, Ms. Hill pushed the students to think about what they needed to know to answer the question. The ideas of open system, closed system and conservation of mass were more important than just defining mass for providing a logical scientific explanation about why mass stayed the same or changed.

The feedback she provided students on their explanations also aligned with the goals of the curriculum including critiques and suggestions about the different components of students' explanations. For example, in Lesson 6 one student read that his reasoning was, "Fat and soap are different substances because of all our investigations had different results." Ms. Hill critiqued his reasoning by saying:

> So in your reasoning, somewhere in you reasoning, you need to refer to whether the properties were the same or different. Were they? Were the properties for fat and soap the same or different? (*Student says "different")* Different. So if the properties are different that means that the substances are what? (*Student says "different"*) Different. And so go back and revise your - I would go back and revise your, your reasoning. We need to see some key terms like properties and substance - in your reasoning.

Ms. Hill critiqued the student's reasoning and provided concrete suggestions on how to improve the scientific explanation. Although Ms. Hill did not engage in the instructional practices as frequently as some of the other teachers, such as Mr. Kaplan, she did consistently incorporate scientific explanations in her classroom and provide her students with support in writing scientific explanations that aligned with the intentions of the curriculum materials.

Ms. Nelson. Ms. Nelson taught in an independent school where her students had a variety of previous experiences and understandings from which to draw upon in terms of writing scientific explanations during the *Stuff* unit. When she first talked about scientific explanation during the unit, she built from students' prior experiences around explanation and argumentation to define scientific explanation as claim, evidence and reasoning in a similar manner to the curriculum. For example, one student initially came up with a definition for evidence as "the data that you have from actually doing something." The discussion continued to develop a more refined definition of evidence. One student said, "You have to have more than one piece of evidence." This comment introduced the idea of providing sufficient evidence. Classroom conversation continued to include other characteristics of evidence such as accuracy and appropriateness. Ms. Nelson summarized their discussion by saying, "So not only does the evidence have to be accurate and we have to have enough of it, but we also need to decide if the evidence is pertinent or not for our claim." Together as a class they developed a definition of evidence including what counted as good evidence (i.e. sufficiency, accuracy, and appropriateness) to support a claim.

During Lesson 6, Ms. Nelson also put three examples of explanations up on the overhead and asked students to critique them. Explanation three did not include reasoning that discusses that different properties determine whether two substances are the same or different. Below is an excerpt from the full class discussion where they discuss the reasoning in explanation three:

> Ms. Nelson: Ok. Molly what do you want to say?
>
> Molly: I like number three.
>
> James: It does not say anything about properties.
>
> Molly: The last sentence says that –
>
> Andrew: Yes, it talks about it.

Molly: - According to the -

Paul: It does not say the word though

Molly: - ones, the properties that we have gone over. Um, that they are different.

Ms. Nelson: Do you think it is ok that it does not have anything about properties? Specifically?

Molly: Yeah, because it has the names of them.

Paul: But, what if we do not know that they are properties?

A couple of students talking at the same time.

Paul: But the point is that to actually tell someone about it, and that is –

David: Right. You are suppose to be able to have some average Joe come up here and be able to understand what you are talking about.

This conversation was characteristic of Ms. Nelson's class, but very different than the classroom discussion typically found in science classrooms in general and specifically in the other five teachers in this study.[1] Traditional science classrooms often consist of a discourse pattern (i.e. IRE) where the teacher initiates a question, the student respond and then the teacher evaluates the response (Lemke, 1990). In the conversation above, Ms. Nelson only asked two questions and the rest of the conversation was driven by the students' critique of the explanations and responses to each other. The student initiative in this conversation suggests that they have taken ownership and understand how to critique the scientific explanations. This last comment that David made reflects an understanding of the importance of including a general science principle in the scientific explanation – so that "some average Joe" would be able to understand. Although Ms. Nelson initially showed her class the examples to model and critique how to write a scientific explanation, the students actually did most of this modeling and critiquing themselves in terms of the problems with the reasoning in the example.

Ms. Nelson did not provide as much support in Lessons 8 and 13 for scientific explanation. For example, when she asked students about what to include in a scientific explanation in Lesson 8, they quickly responded "Claim, evidence, and reasoning." Her students appeared to have a strong understanding of the general explanation framework. Ms. Nelson seemed to use the instructional strategies when she felt like there was a particular need. For example, she modeled how to construct an explanation in Lesson 13 when students were confronted with a new content area and provided students with individual feedback when they asked her specific questions about their explanations. Although she provided considerable support in Lesson 6, she engaged in fewer instructional strategies in the later lessons though her support always aligned with the goals in the unit in terms of scientific explanation.

Summary. Across the six teachers, they are a variety of similarities and differences in terms of how they discussed and supported scientific explanation in their classrooms. One pattern that emerged was whether the teacher's definition of scientific explanation aligned with

[1] In the original coding scheme I did not look for the IRE discourse structure. Often in case studies the researcher has to recognize the need and development of late emerging issues and codes (Stake, 2000). When this different pattern of discourse emerged from Ms. Nelson's classroom discussion, I re-examined the classroom discussions in the other teachers' classrooms. This confirmed that she was the only teacher to frequently diverge from using the IRE structure in her classroom.

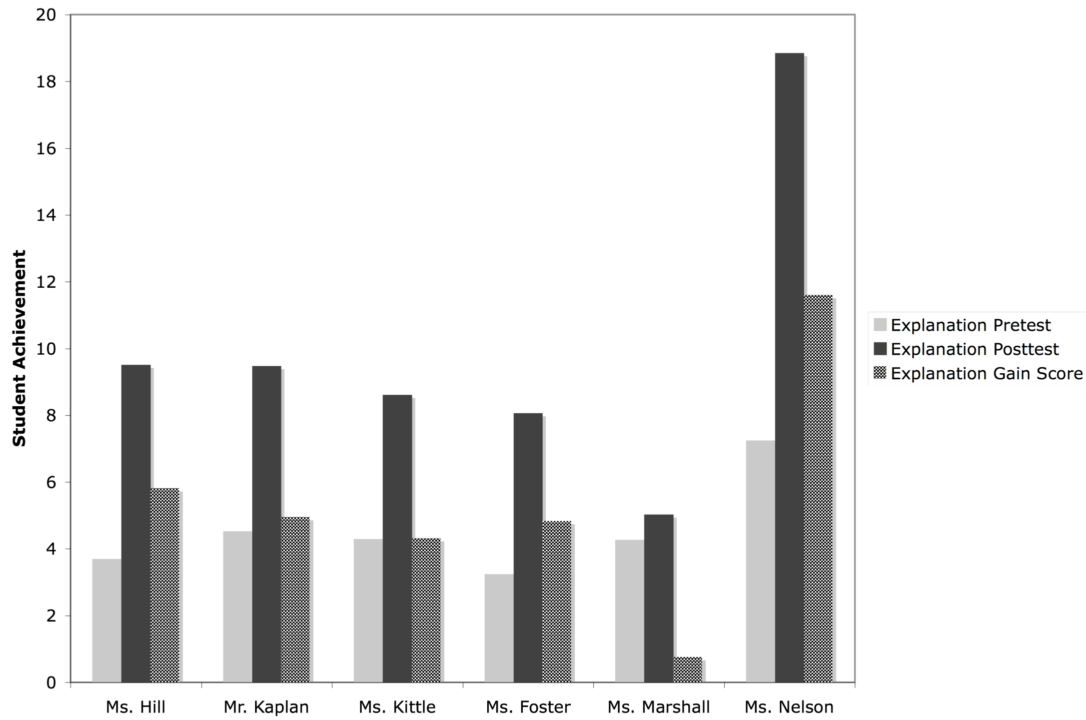
the definition provided by the curriculum materials and the curricular scaffolds. Mr. Kaplan, Ms. Hill and Ms. Nelson all provided similar definitions compared to that in the curriculum materials though with a range of explicitness. Ms. Marshall and Ms. Foster provided modified definitions of scientific explanation where instead of talking about a scientific explanation consisting of claim, evidence, and reasoning, they discussed explanations as consisting of claim, definition, evidence, and therefore/conclusion. Ms. Kittle discussed scientific explanation as consisting of claim, evidence, and reasoning, but provided a modified definition of reasoning. In Ms. Kittle's case she appeared to be trying to change her previous definition of reasoning as a "definition" to include more of a conversation about connecting the claim and evidence to more closely align with the definition of reasoning provided in the *Stuff* unit. Overall, some of the teachers engaged in instructional practices that aligned with the scientific explanation learning goal of the unit and complemented the goals of the unit (i.e. Mr. Kaplan, Ms. Hill, Ms. Nelson and to some degree Ms. Kittle), while the other two teachers (i.e. Ms. Marshall and Ms. Foster) engaged in instructional practices that were in conflict with the explanation goals of the *Stuff* unit.

Student Learning of Explanation by Teacher

I examined whether there was differential student learning of scientific explanation and the science content across the six different teachers. Initially, to determine whether student learning varied by teacher I ran an analysis of covariance, ANCOVA, with the teacher as the fixed factor, the pretest score as the covariate, and the gain score as the outcome variable. I completed this analysis for students' total scientific explanation scores, claim scores, evidence scores, reasoning scores and their multiple-choice scores. In all five analyses, the effect of teacher was significant, the pretest score as a covariate was significant, but there was not a significant interaction between the pretest score and the teacher. Since in all cases there was not a significant interaction, I decided to run an analysis of variance, ANOVA, for students' gain scores using a post hoc Tukey test, which allowed me to compare each pair of teachers to determine where the significant difference occurred. I only report the F values and significance from the ANOVAs.

There was a significant teacher effect in terms of student learning of scientific explanation. Figure 1 provides the pretest, posttest and gain scores for each teacher for the whole explanation score.

Figure 1: Teacher Effect on Students' Scientific Explanations

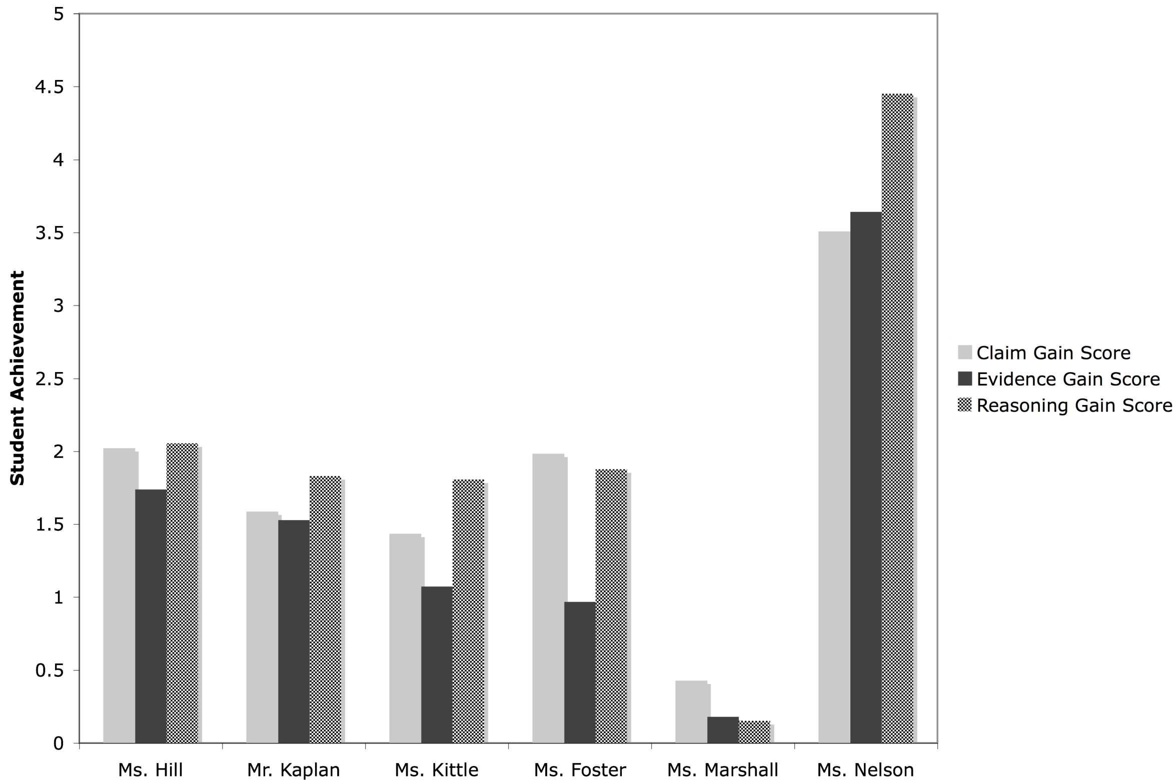


I include the pre and posttest scores to illustrate that Ms. Nelson's students are both beginning and ending the unit at very different achievement levels than the students of the five teachers in the urban area. Her case is unique in terms of the context, so it is not simply her instructional practices that influenced her different student achievement over the course of the *Stuff* unit.

To investigate where the teacher effects occurred, I ran an analysis of variance, ANOVA, with a post hoc Tukey test for students' explanation pretest scores and learning gains. Not surprisingly, both ANOVAs were significant for the pretest, $F\ (5, 322) = 6.72$, $p < .001$, and for the gain scores, $F\ (5, 322) = 31.24$, $p < .001$. I ran the pretest because I was interested in whether the teachers' students were starting the unit with different overall achievement in terms of scientific explanation. On the pretest, the only significant difference in student achievement was between Ms. Nelson's students and the other five teachers. Ms. Nelson's students scored significantly higher when compared to the students from each of the other five teachers, $ps < .001$. This suggests that the students in all five urban schools started with similar performance in terms of writing scientific explanation. For the gain scores, there was a significant difference between Ms. Marshall's students' scores and the other five teachers and between Ms. Nelson's students' scores and the other five teachers, $ps < .01$. Ms. Nelson's students had the greatest gains out of all six teachers, while Ms. Marshall's students had the lowest gains for their total explanation score.

I also investigated whether there were significant differences in student learning for the three components of scientific explanation (e.g. claim, evidence, and reasoning) across the teachers. Figure 2 provides the results for students' claim, evidence and reasoning gain scores by teacher.

Figure 2: Teacher Effect on Students' Claims, Evidence and Reasoning



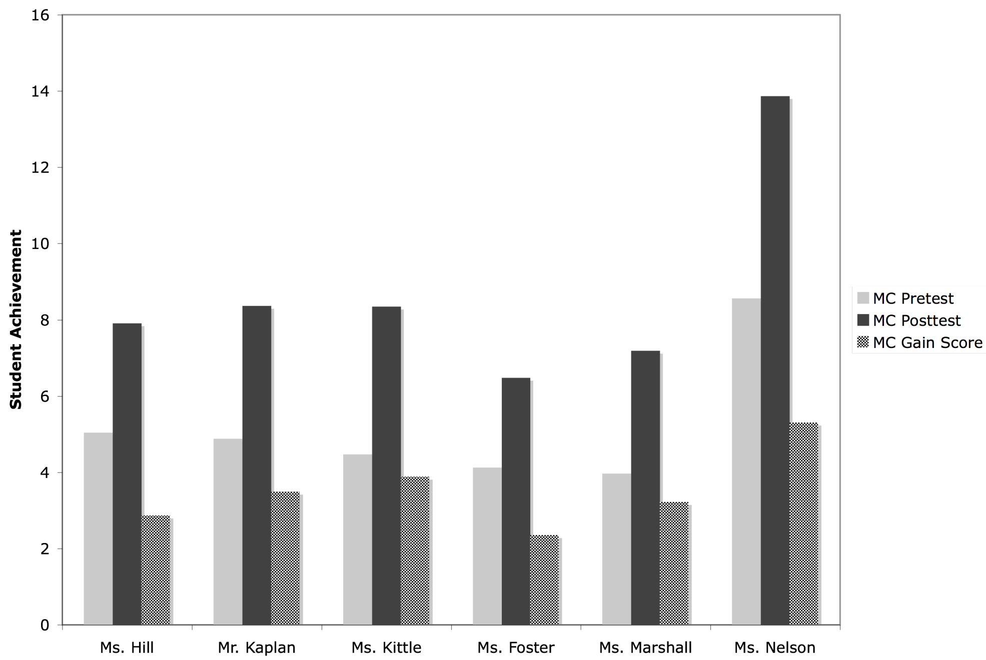
Again, to determine where the difference occurred between teachers, I ran an analysis of variance, ANOVA, with a post hoc Tukey test for students' learning gains for claim. The ANOVA for students' gain scores for claim was significant, F (5, 322) = 6.56, $p < .001$. In terms of students' claim gain scores, Ms. Nelson's students had significantly greater gains in their claim scores compared to Ms. Marshall's, Ms. Kittle's and Mr. Kaplan's students. There was not significant difference between any other pair of teachers.

The ANOVA for students' gain scores for evidence was also significant, F (5, 322) = 16.75, $p < .001$. The post hoc Tukey tests showed that there were significant differences between some pairs of teachers. Ms. Nelson's students had greater learning gains compared to each of the five other teachers, *ps* < .01. Ms. Marshall's students had significantly lower learning gains compared to Ms. Nelson, Ms. Hill and Mr., Kaplan, but similar learning gains compared to Ms. Kittle and Ms. Foster.

Finally, I examined the reasoning scores for the students of each teacher. There was a significant difference for the ANOVA for students' gain scores for reasoning across the six teachers, F (5, 322) = 16.75, $p < .001$. Similar to the results for the overall scientific explanation score, Ms. Nelson's students achieved greater student learning gains for reasoning compared to the students of the other five teachers and Ms. Marshall's students achieved lower student learning gains, *ps* < .001. There was not a significant difference between Ms. Hill's, Mr. Kaplan's, Ms. Marshall's and Ms. Kittle's students' learning of reasoning during the *Stuff* unit. Interesting to note, all of the students' initial reasoning started very low. At the beginning of the unit, students were not explicitly providing a justification for the appropriateness of their claims and evidence. By the end of the unit, more students are including reasoning in their scientific explanations, but this is still the most challenging component for students.

I also examined students' understanding of the content as measured by the multiple-choice items to see if their understanding varied by teacher. The ANOVA showed that there was a significant difference in student learning of the content knowledge as measured by the multiple-choice items across the six different teachers, F (5, 322) = 5.92, p < .001. Figure 3 displays the results from this analysis.

Figure 3: Teacher Effect on Students' Content Knowledge



Interestingly, in many of the previous analyses focused on scientific explanation, Ms. Marshall's students had significantly lower learning gains compared to the other five teachers' students. In this analysis of the science content, her students' learning is similar to the other four teachers in the urban schools. Ms. Marshall's students have a similar understanding of the science content, but they have a difficult time writing scientific explanations. This suggests that just understanding the science content is not sufficient to write a strong scientific explanation. Rather, to receive a high score for written explanations required both an understanding of the science content and how to write a scientific explanation. The only significant difference in learning in this case was between Ms. Nelson's students and the students of the other five teachers, *ps* < .05.

Summary of findings. Overall, Ms. Nelson's students began the unit with stronger written scientific explanations and achieved greater student learning gains for the composite explanation, evidence, reasoning, and multiple-choice scores compared to the students of the other five teachers.

Ms. Marshall's students did not have lower achievement on their pretest explanation scores compared to the other four teachers in the urban area. Yet her students had lower gains for the composite explanation score and reasoning compared to all five of the other teachers. For evidence, Ms. Marshall's students had significantly lower learning gains compared to the students of Ms. Nelson, Ms. Hill and Mr. Kaplan, but similar learning gains compared to the students of Ms. Kittle and Ms. Foster.

Mr. Kaplan's, Ms. Foster's, Ms. Kittle's, and Ms. Hill's students had similar learning gains for the science content and a variety of the different measures of scientific explanation. One significant difference in their students' learning was for evidence. The students of Mr. Kaplan and Ms. Hill had greater learning gains for evidence compared to the students of Ms. Foster and Ms. Kittle.

Relationship Between Instructional Practices and Student Learning

Ms. Marshall made the greatest changes to the *Stuff* unit during her enactment, used a different definition of scientific explanation that did not align with the curriculum and her students had the lowest learning gains in terms of scientific explanation. Interestingly, her students still had strong learning gains in terms of their multiple-choice scores. This suggests that just understanding the science content is not enough to result in students being able to write scientific explanations.

There were little differences in the student learning of Mr. Kaplan, Ms. Foster, Ms. Kittle and Ms. Hill even though the way they defined scientific explanation and used the different instructional practices did vary. Interestingly, Mr. Kaplan's and Ms. Hill's students had higher learning gains for evidence, but not for reasoning. Two possible explanations of this are because the students still struggled with the reasoning component or limitations in the coding scheme for assessing students' written explanations. Both of these possibilities are discussed in more detail in the discussion.

Ms. Nelson's students had the greatest learning gains for both scientific explanation and their multiple-choice scores, which may be because she completed more of the unit than the other teachers and she engaged in numerous instructional practices during the unit to support her students. Her definition of scientific explanation built off her students' prior knowledge, was explicit and matched the definition provided in the curriculum materials. She actively engaged her students in the discussions about scientific explanation and was the only teacher not to engage in traditional IRE classroom discourse. Rather her students actively listened and responded to each other playing an important role in the direction of the conversation and exhibiting a strong understanding of the scientific explanation framework.

Discussion

In terms of scientific explanation and argumentation, the role of the teacher is valued as important (Osborne et al., 2004; Tabak, 2004). In previous work with my colleagues (McNeill & Krajcik, in press), we found that when teachers discussed the rationale behind scientific explanation in combination with defining and discussing scientific explanation as claim, evidence, and reasoning, the result was greater student learning of scientific explanation. The sample size of six teachers in this study does not allow me to make causal claims about the effect of specific instructional practices on student learning. Yet this more in depth descriptive study is important in that it illustrates what instructional practices were used in the classrooms, the complexity in how those practices were used, and the importance of how the teachers defined scientific explanation in their classroom. Furthermore, the study shows that the teachers' enactments of the curriculum were not always congruent with the intended learning goal for scientific explanation, which may have influenced students' learning of scientific explanation.

In this study, all six teachers used the same curriculum unit, *How can I make new stuff from old stuff?*, in which scientific explanation was an explicit goal. Although the teachers used the same materials, they engaged in a range of instructional practices in their classroom to support students in scientific explanation. All six teachers defined scientific explanation in some way and modeled how to construct scientific explanations. Yet the frequency and quality of these two practices varied, as well as whether the teachers engaged in the other instructional practices such as making the rationale explicit, connecting to everyday explanations, providing feedback to students, and connecting to students' prior knowledge. The adoption of a curricular unit will not result in uniform instruction (Remillard, 2005). Whenever teachers enact curriculum materials there is going to be a range in those enactments. Furthermore, there is a range of acceptable enactments of a curriculum and it is important for curriculum developers to clarify the essential components (Remillard, 2005). Providing teachers with a variety of productive instructional strategies may help them in the challenging task of creating inquiry-oriented classrooms.

We designed the curriculum to be educative in that it was specifically designed to promote teacher learning (Ball & Cohen, 1996; Davis & Krajcik, 2005). Although the materials discuss the instructional practices to support scientific explanation, all six teachers only consistently used two in their classrooms, defining and modeling scientific explanation. Furthermore, three of the teachers modified the definition of scientific explanations. Half the teachers discussed the rationale behind scientific explanation, only two teachers connected to everyday explanations, and the frequency and quality of providing students feedback and connecting to students' prior knowledge also varied. This leads to the question of how effective were the educative features in the *Stuff* unit and how could they be designed to better support teacher learning. The goal of this study was not to specifically investigate the influence of the educative features. Yet the variation in teachers' use of the instructional practices suggests that this is an important topic for future research.

Teachers' Definitions of Scientific Explanation

One trend in the teachers' enactment of the *Stuff* unit was in how they defined scientific explanation and made scientific explanation explicit for their students. Of the six instructional practices, the case studies suggest that this instructional practice was particularly important for characterizing the support the teachers provided their students. The way the teachers defined scientific explanation varied and influenced the way they used the other instructional practices in their classrooms. Three of the teachers chose to modify this framework or definition of scientific explanation to varying degrees, which did not fully align with the scientific explanation learning goal of the *Stuff* unit.

The teachers in the urban area had the opportunity to attend professional development workshops in which lead teachers facilitated activities and discussions around issues centered on the reform based curriculum materials, including the *Stuff* unit (Fogleman et al., 2006). The workshops included discussions of scientific explanation, which differed from the way scientific explanation was discussed in the curriculum materials. These discussions may have influenced the modifications that some of the teachers made to the definition of scientific explanation. Ms. Marshall and Ms. Foster modified the definition the most in that they discussed scientific explanation as claim, definition, evidence, and therefore/conclusion. Ms. Kittle still defined scientific explanation as claim, evidence, and reasoning, but she initially provided her students with a modified definition of reasoning that she tried to change over time to more closely align with the curriculum materials.

Ms. Foster and Ms. Marshall used modified definitions of scientific explanation that were an even greater simplification of the complex practice of constructing a scientific explanation than the one suggested in the curriculum materials. Their definitions of scientific explanation were not congruent with the learning goal of the curriculum. These teachers provided students with more of a formula or algorithm for their writing that they could apply with minimal reflection on the actual context. For the component of scientific explanation that they referred to as the "definition", they told their students to choose a word in the question or their claim and define it. Then for students' "therefore" or "conclusion," the teachers asked their students to repeat the claim and evidence. This is an easier and less complex task then asking students to provide their "reasoning" where they provide a justification for why their evidence supports their claim using appropriate scientific principles. Blumenfeld and Meece (1988) discuss reasons why a teacher might choose to simplify a task:

> …high-level cognitive tasks are associated with low completion rates and high error rates; these factors slow the momentum of a lesson and pressure teachers to simplify material and suspend accountability. To avoid student failure and ensure student cooperation and participation, teachers invent ways to modify difficult assignments and decrease cognitive requirements. Consequently, tasks that initially required students to practice complex problem-solving skills can be transformed into those that merely require guessing the correct answer. (p. 238)

Ms. Marshall's and Ms. Foster's modified definitions of scientific explanation decreased the problem solving required to successfully complete this complex task. They made the task easier and increased the probability that their students would be able to successfully complete this newly defined task.

Ms. Marshall's and Ms. Foster's adaptations also more closely aligned scientific explanation to the instructional norms Haberman (1991) describes as the "pedagogy of poverty" often found in urban schools. The pedagogy of poverty is characterized by an authoritarian and directive nature with a focus on low-level skills in which students can succeed without being thoughtful. If this type of pedagogy is the norm in a school, Haberman argues that it is difficult for one teacher to transcend that norm and successfully engage students in complex problem solving when that is not a typical expectation of students. Ms. Marshall's and Ms. Foster's adaptations of the scientific explanation framework to a simpler and less cognitively demanding task may have been influenced by their school cultures, which may not have typically engaged students in this type of inquiry and complex problem solving.

Not only did this modified framework influence how Ms. Marshall and Ms. Foster defined scientific explanation, but it also influenced how they modeled explanations in terms of the examples they provided their students and the features they pointed out to their students. The examples included a definition of a word instead of reasoning in which there was a justification for why the evidence supported the claim. Their definitions of scientific explanation also influenced the feedback they provided their students on their own explanations. For example, Ms. Foster would remind students to include CDEC in their explanations, which stood for claim, definition, evidence, and conclusion. The way the teachers defined scientific explanation influenced the other instructional practices that they used in their classrooms. This finding aligns with the work of Osborne and his colleagues in terms of the influence of teacher beliefs about argumentation on their classroom practice. In classroom instruction, teacher differences in their emphasis on argument may be a result of their varied understandings of what counts as an argument (Erduran, Simon & Osborne, 2004). The different instructional practices Ms. Marshall and Ms. Foster used in their classrooms may be the result of their different beliefs about what counts as a scientific explanation. As I will discuss below under limitations and future work, I did not specifically study teachers' beliefs or why they made the choices that they did. This is an important area for future research to develop a better understanding of the variation in teachers' enactments and instructional support for scientific explanation.

Ms. Kittle defined scientific explanation as claim, evidence, and reasoning yet she provided her students with a modified definition of reasoning. Before the *Stuff* unit, she had defined reasoning as "define the scientific principle." During the unit, she tried to modify her definition of reasoning to encourage her students to connect that definition to both their claim and evidence to be more consistent with the curriculum materials. In her case, the curriculum materials may have influenced her own understanding of scientific explanation and consequently had an impact on her instructional practice.

Relationship Between Instructional Support and Student Learning

There was a relationship between the teachers' different instructional support for scientific explanation and their students' learning. Ms. Marshall's students had the lowest learning gains compared to the other five teachers for scientific explanations. She made the largest modifications to the unit in terms of scientific explanations, which did not align to the learning goals of the *Stuff* unit. She only had students write scientific explanations in one of the three focal lessons and provided students with limited support. This may be why her students had lower learning gains in terms of scientific explanation. Yet, her students did not have different learning gains compared to the students from the other four urban teachers in terms of the multiple-choice items measuring content knowledge. This suggests that students' success at writing scientific explanations required more than an understanding of just the science content. The specific explanation rubrics used in this study measured students' ability to write scientific explanations for this particular science content. In order to receive a high score, students need both an understanding of the science content and an understanding of the general scientific explanation framework. Ms. Marshall's students demonstrated that they understood the science content based on their performance on the multiple-choice items, so their inability to write strong scientific explanations suggests that they did not have knowledge about how to write scientific explanations. The students of the other five teachers who were exposed to the curricular scaffolds and received instructional support for scientific explanation achieved greater learning in terms of their ability to write scientific explanations.

Surprisingly, there were little differences in the student learning of Mr. Kaplan, Ms. Foster, Ms. Kittle and Ms. Hill. Mr. Kaplan's and Ms. Hill's students have higher learning gains for evidence, but not for reasoning. Based on the different ways that Ms. Foster and Ms. Kittle defined scientific explanation or reasoning, one might expect that there would be a difference in their students' reasoning scores. Similar to previous work (Bell & Linn, 2000; McNeill et al., 2006), the reasoning was the most difficult aspect for students. Across all of the teachers, students' reasoning scores were lower compared to their claim and evidence scores. Perhaps no difference arose for reasoning because the students for all four of the teachers were still struggling with this aspect of scientific explanation. Another possibility is that the coding scheme for reasoning did not capture the logical coherence of the reasoning, which was the major difference in the discussions of reasoning in Mr. Kaplan's and Ms. Hill's classrooms compared to Ms. Foster and Ms. Kittle. In their reasoning, students' explanations should articulate why their data counts as evidence for their particular claim using appropriate scientific principles. Perhaps the coding scheme was not able to sufficiently distinguish between this type of a justification and simply defining an appropriate term.

Finally, Ms. Nelson's students had the greatest learning gains for both scientific explanations and their content knowledge as measured by the multiple-choice scores. Ms. Nelson's context and enactment were unique in a variety of ways. First, she was the only teacher to teach in an independent school in a large college town in which the majority of students were Caucasian and not eligible for free or reduced lunch. The other five teachers taught in urban schools whose students were predominately African American and the majority of whom were eligible for free or reduced lunch. Ms. Nelson's students also began the unit with greater prior knowledge as measured by the pretest scores for both scientific explanation and the content. Because of Ms. Nelson's uniquely different context, I cannot attribute the greater learning gains solely to her enactment. The greater learning gains may be the result of her different context.

Yet there are a number of unique characteristics about Ms. Nelson's enactment and instructional practices. First, she was the only teacher to complete the entire unit. Furthermore, she engaged in numerous instructional practices that aligned with the goals of the curriculum unit with a unique focus on building off students' prior knowledge and providing formative written feedback. For example, she built off students' prior knowledge when she defined scientific explanation by having the students initially provide the definitions. Furthermore, the discourse patterns in her classroom were unique compared to the other teachers and more traditional science classrooms. Traditional science classrooms often consist of a discourse pattern (i.e. IRE) where the teacher initiates a question, the students respond and then the teacher evaluates the response (Lemke, 1990). Crawford (2000) argues for collaborative inquiry in which the learning environment does not consist of a teacher-centered model, but rather a collaborative model where teachers and students work together through shared learning experiences. In Ms. Nelson's classroom, the students played a more predominant role in the conversation often directly asking and answering each other's questions. Finally, she provided her students with considerable written formative feedback. Formative feedback that focuses on what needs to be done with the specific goal of helping students learn can improve student performance (Black, 2003). If Ms. Nelson had provided less support, I conjecture that even in this unique school context her students would not have had as large learning gains. Her practices played an important role in student learning. But in order to develop a more complete understanding of the influence of her practices, I would need to compare her students' learning gains to students in a similar context, but who received different instructional support from their teacher.

Finally, this study does not address why the teachers made the choices that they did in enacting the curriculum. The enactment of curriculum materials is a dynamic process influenced by a teacher's knowledge and beliefs (Remillard, 2005). Teachers' beliefs about what counts as an argument may influence their classroom instruction (Erduran, Simon & Osborne, 2004). Teachers' beliefs about the role of curriculum materials could also influence how they decided to use the materials. In this study, the question remains about whether the beliefs of Ms. Marshall and Ms. Foster were similar and different from the other four teachers in the study. Why did they choose to prioritize a modified definition of scientific explanation? Were their choices based on their beliefs about what counted as a scientific explanation or appropriate scientific discourse? Were their choices influenced by how the viewed the role of curriculum materials compared to professional development experiences? In Ms. Foster's case, it appeared to be a deliberate choice, while it is not clear whether Ms. Marshall saw her learning goals for scientific explanation as the same or different compared to the curriculum materials. Future work should examine how teachers' beliefs and knowledge influence the choices they make in enacting inquiry oriented curriculum materials.

Acknowledgements

This research was conducted as part of the Investigating and Questioning our World through Science and Technology (IQWST) project and the Center for Curriculum Materials in Science (CCMS), supported in part by the National Science Foundation grants ESI 0101780 and ESI 0227557 respectively. Any opinions expressed in this work are those of the author and do not necessarily represent either those of the funding agency or Boston College. I would like to thank Joe Krajcik, Betsy Davis, Brian Reiser, Priti Shah, Lisa Kenyon, Leema Kuhn, and Meredith Houle for their discussions and feedback on this work. I would also like to thank Olivia McKinney and Ellen Krajcik for all of their help in coding the data.

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher, 25*(9), 6-8, 14.

Bell, P., & Linn, M. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education, 22*(8), 797-817.

Black, P. (2003). The importance of everyday assessment. In J. M. Atkin & J. E. Coffey (Eds.), *Everyday assessment in the science classroom* (pp. 1-11). Arlington, VA:

NSTA Press.

Blumenfeld, P. & Meece, J. L. (1988). Task factors, teacher behavior, and students' involvement and use f learning strategies in science. *The Elementary School Journal, 88*(3), 235-250.

Bransford, J., Brown, A., & Cocking, R. (Eds.). (2000). *How people learn: Brain, mind, experience and school.* Washington D.C.: National Academy Press.

Chin, C. & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching, 37*(2), 109-138.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916-937.

Davis, E. A. & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3-14.

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's ideas in science.* Philadelphia: Open University Press.

Driver, R., Newton, P. & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287-312.

Erduran, S., Simon, S. & Osborne, J. (2004) TAPing into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88*(6), 915-933.

Fogleman, J., Fishman, B., & Krajcik, J. (2006). Sustaining innovations through lead teacher learning: A learning sciences perspective on supporting professional development. *Teaching Education, 17*(2), 181-194.

Fogleman, J. & McNeill, K. L. (2005, April). *Comparing teachers' adaptations of an inquiry-oriented chemistry unit.* Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Flick, L. B. (2000). Cognitive scaffolding that fosters scientific inquiry in middle level science. *Journal of Science Teacher Education, 11*(2), 109-129.

Fradd, S. & Lee, O. (1999). Teachers' roles in promoting science inquiry with students from diverse language backgrounds. *Educational Researcher*, 18, 14-20.

Haberman, M. (1991). The pedagogy of poverty versus good teaching. *Phi Delta Kappan*, *73,* 190-294.

Harris, C. J., McNeill, K. L., Lizotte, D. L., Marx, R. W. & Krajcik, J. (2006). Usable assessments for teaching science content and inquiry standards. In McMahon, M., Simmons, P., Sommers, R., DeBaets, D., & Crowley, F. (Eds.), *Assessment in science: Practical experiences and education research* (pp. 67-88). Arlington, VA: National Science Teachers Association Press.

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A Sociocognitive Approach. *The Journal of the Learning Sciences. 8*(3&4), 451-493.

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38*(6), 631-645.

Krajcik, J., McNeill, K. L. & Reiser, B (in review). *Learning-goals-driven design model: Curriculum materials that align with national standards and incorporate project-based pedagogy.*

Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The development of cognitive skills to support inquiry. Cognition and Instruction, 18(4), 495-523.

Lemke, J. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing Corporation.

McGinn, M. K. & Roth, W-M. (1999). Preparing students for competent scientific practice: Implications of recent research in science and technology studies. *Educational Researcher, 28*(3), 14-24.

McNeill, K. L. (2006). *Supporting students' construction of scientific explanations through curricular scaffolds and teacher instructional practices.* Unpublished Doctoral Dissertation, University of Michigan, Michigan.

McNeill, K. L., Harris, C. J., Heitzman, M., Lizotte, D. J., Sutherland, L. M., & Krajcik, J. (2004). How can I make new stuff from old stuff? In J. Krajcik & B. J. Reiser (Eds.), *IQWST: Investigating and questioning our world through science and technology*. Ann Arbor, MI: University of Michigan.

McNeill, K. L. & Krajcik, J. (in press a). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching.*

McNeill, K. L. & Krajcik, J. (in press b). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In Lovett, M & Shah, P (Eds.) *Thinking with Data: the Proceedings of the 33rd Carnegie Symposium on Cognition.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

McNeill, K.L. & Krajcik, J. (2007, April). Relationship between teacher instructional practices and curricular scaffolds in supporting students in writing scientific explanations. Paper to be presented at the annual meeting of the American Educational Research Association, Chicago, Il.

McNeill, K. L., Lizotte, D. J, Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*(2), 153-191.

Metz, K. E. (2000). Young children's inquiry in biology: Building the knowledge bases to empower independent inquiry. In J. Minstrell & E. H. van Zee (eds.), *Inquiry into inquiry learning and teaching in science* (pp. 371-404). Washington, DC: American Association for the Advancement of Science.

Miles, M., & Huberman, A. M. (1994). Qualitative data analysis: An expanded sourcebook (2nd edition). Thousand Oaks, CA: Sage.

Moje, E. B., Collazo, T., Carrillo, R., & Marx, R. W. (2001). "Maestro, what is quality?" language, literacy, and discourse in project-based science. *Journal of Research in Science Teaching, 38*(4), 469-498.

Moje, E. B., Peek-Brown, D., Sutherland, L. M., Marx, R. W., Blumenfeld, P., & Krajcik, J. (2004). Explaining explanations: Developing scientific literacy in middle-school project-based science reforms. In D. Strickland & D. E. Alvermann, (eds.), *Bridging the Gap: Improving Literacy Learning for Preadolescent and Adolescent Learners in Grades* (pp. 4-12). New York: Carnegie Corporation.

Nagel, E. (1961). The structure of science: Problems in the logic of science education. New York, NY: Harcourt, Brace, & World, Inc.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

Osborne, J., Erduran, S., & Somin, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994-1020.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *The Journal of the Learning Sciences, 13*(3), 423-451.

Puntambekar, S., Stylianou, A., Goldstein, J. (2007). Comparing classroom enactments of an inquiry curriculum: Lessons learned from two teachers. *Journal of the Learning Sciences, 16*(1), 81-130.

Quintana, C., Reiser, B., Davis, E. A., Krajcik, J., Fretz, E., Golan, R, Kyza, E., Edelson, D. & Soloway, E. (2004). A scaffolding design framework for designing educational software. *The Journal of the Learning Sciences*, *13*(3), 337-386.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211-246.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634-656.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *The Journal of the Learning Sciences, 12*(1), 5-51.

Sandoval, W. A. & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction, 23*(1), 23-55.

Schneider, R., Krajcik, J. & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching, 42*(3), 283-312.

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi*-experimental designs for generalized causal inference. Boston, MA: Houghton Mifflin Company.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2-3), 235-260.

Stake, R. E. (2000). Case Studies. In N. K. Denzin & Y. S. Lincoln (Eds.). *Handbook of Qualitative Research.* Thousand Oaks, CA, Sage.

Tabak, I. (2004). Synergy: A complement to emerging patterns in distributed scaffolding. *Journal of the Learning Sciences, 13*(3), 305-335.

Tabak, I., & Reiser, B. J. (1997). Complementary roles of software-based scaffolding and teacher-student interactions in inquiry learning. In R. Hall, N. Miyake & N. Enyedy (Eds.), Proceedings of Computer Support for Collaborative Learning '97 (pp. 289-298). Toronto, Canada.

Toulmin, S. (1958). *The uses of argument.* Cambridge, UK: Cambridge University Press.

van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., Plantin, C., Walton, D. N., Willard, C. A., Woods, J., & Zarefsky, D. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments*. Mahwah, NJ: Lawrence Erlbaum Associates.