The effect of professional development on teachers' beliefs and pedagogical content knowledge for supporting students in scientific argumentation

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One of the hallmarks of science is the production of new knowledge about the natural world through objective argument and critique (Osborne, 2010). This same goal of scientific argumentation is also prevalent in recent science education reform documents (Duschl, Schweingruber, & Shouse, 2007) and in the preliminary public draft of the frameworks for science education (NRC, 2010). Although argumentation is viewed as an essential goal, it rarely occurs in k-12 science classrooms (Newton, Driver & Osborne, 1999). One potential avenue for supporting greater argumentation in classroom practice is through professional development that focuses on this key scientific inquiry practice (Simon, Erduran, & Osborne, 2006). Consequently, our research looks to address the following research question: What are teachers' pedagogical content knowledge and beliefs for scientific argumentation while participating in professional development focused on this topic?

Teachers' Pedagogical Content Knowledge and Beliefs

In order to support students in successfully engaging in argumentation, classroom instruction should include both explicit teaching of argumentation and meta-linguistic features of argumentation, such as a framework that discusses different components such as claim and evidence (Osborne, 2010). Yet teachers' lack pedagogical strategies to support students in this complex practice (Zohar, 2008). Simon and her colleagues (2006) argue that for teachers to change their classroom practice they need professional development experiences that focus on teachers' existing understanding of evidence, explanation, and argumentation. We cannot expect teachers to incorporate explanation and argumentation into their classrooms if they do not have stronger understandings of these scientific inquiry practices (Zembal-Saul, 2009). Teachers require pedagogical content knowledge (PCK) for scientific inquiry practices or knowledge of how to teach students to engage in scientific inquiry practices (Davis & Krajcik, 2005). Furthermore, teacher beliefs about instructional strategies and their effectiveness impact teachers' willingness to use inquiry-based instruction in their classroom (Johnson, 2009). Yet there is currently little research in the field focused on teachers' understandings and beliefs or teacher education in this area of scientific explanation and argumentation (Zohar, 2008).

The Role of Professional Development

Our model of teacher learning is grounded in the importance of linking current science education research to classroom practice. Teachers learning experiences should be grounded in authentic k-12 classroom practice, such as using cases of k-12 teaching (Putnam & Borko, 2000). Using examples of student writing and videotapes of classroom practice is one method of connecting theory to the k-12 setting. Observing videotapes of classroom discussion can provide opportunities to think deeply about students' comments and carefully consider classroom interactions (Sherin, 2000). Furthermore, it can be important to provide teachers examples from classrooms with diverse learners. The diversity in the student population in public schools across the nation continues to grow in terms of students' backgrounds and language experiences (Planty et al., 2007). Teachers often think that higher order thinking skills, like argumentation, should or can only be taught to high ability students (Zohar, 2008). Using examples from diverse students for both writing and videotapes of classroom is important to illustrate to teachers that using evidence to support explanations of phenomena can be achieved by all students.

Specifically, in terms of scientific explanation and argumentation there has been little research on how to best support teachers to incorporate this important practice into their own classrooms. Zembal-Saul and her colleagues have done some of the only research specifically focusing on supporting teachers in scientific argumentation. They found that placing more emphasis on argumentation in science methods classes through the use of video cases, can encourage pre-service teachers to focus more on the purpose of learning science and the importance of classroom discourse in science teaching. The pre-service teachers became more likely to think about the role of evidence, explanation and argumentation in science classroom and how to incorporate these important scientific practices into their own teaching (Zembal-Saul, 2005). Teachers need to not only understand the importance of scientific explanation and argumentation, but they need to see how it can be integrated into classroom practice to support a variety of different students in constructing scientific explanations. In this study, we examined teachers' beliefs and pedagogical content knowledge for argumentation as they engaged in professional grounded in authentic k-12 classroom practice.

METHOD

Professional Development Workshops

This study took place in the context of three professional development series focused on supporting students in scientific argumentation. All three series consisted of three workshops and included between twenty and twenty-five participants. The first workshop was a 7 ½ hour Saturday workshop that focused on the importance of scientific argumentation, introduced the claim, evidence, and reasoning (CER) framework, and provided teachers with an opportunity to design an initial learning task to introduce the framework to their students. The second workshop was approximately one month later after school for 3 ½ hours. During the second workshop, teachers shared samples of student writing and discussed challenges and strengths from their classrooms. The rest of the workshop focused on introducing a variety of different teaching strategies to support students in CER and having the teachers design a second lesson that integrated the teaching strategy. The third and final workshop occurred approximately one month later again after school for 3 ½ hours. During the last workshop, the teachers again shared student work and discussed challenges and successes. The reminder of the workshop focused on using the framework to support classroom talk, designing scientific argumentation assessments and designing and using rubrics to inform instruction. Each teacher who attended the workshop was provided with a draft version of the book, *Supporting grade 5-8 students in constructing explanations in science: The claim, evidence and reasoning framework for talk and writing* (McNeill & Krajcik, 2012) and was asked to read specific chapters between each of the meetings. Table 1 provides a summary of the professional development activities and the associated home work assignments to be completed between each session. The videos used during the workshop sessions can be found in McNeill and Krajcik (2012) and the activities, student writing, rubrics and transcripts can be found in McNeill and Krajcik (2012a).

Table 1: Description of Professional Development Series

Session	Agenda	Homework
Session 1 7 ½ hours	• *Chemistry Investigation*: In groups, teachers conduct chemical reaction investigation and write an ideal 7th grade scientific argument. Share writing across groups and discuss strengths and weaknesses. • *Presentation on Importance and Framework*: Facilitators present on the importance of scientific argumentation, introduce the claim, evidence, and reasoning (CER) framework and share color coded student examples of written arguments. • *Video of 7th Grade Classroom*: Watch and discuss a video of a 7th grade classroom in which the teacher introduces her students to claim, evidence and reasoning. • *Analyze Student Writing*: In groups, teachers analyze samples of 7th grade writing from the chemical reaction investigation. Discuss the strengths and weaknesses of the student examples. • *Presentation on Student Challenges*: Facilitators present on common student challenges with argumentation. • *Presentation on Designing Learning Tasks*: Facilitators present on how to design learning task that support argumentation. • *Design Learning Task*: In groups, teachers design a learning task to introduce argumentation to their students.	• Read Chapters 1-3 of book (McNeill & Krajcik, 2012) • Try argument learning task with students • Bring 6 samples of student writing (2 stronger, 2 middle, 2 weaker) to Session 2.
Session 2 3 ½ hours	• *Share Student Writing*: In groups, teachers shared their 6 samples of student writing as well as the challenges and successes. • *Full Class Discussion*: Share across the different groups lessons learned from the lesson as well as questions for future lessons. • *Videos of Grade 5-8 Classrooms*: Watch and discuss eight video clips illustrating teaching strategies: 1) Discuss the framework, 2) Connect to everyday examples, 3) Provide a rationale, 4) Connect to other content areas, 5) Model and critique examples, 6) Provide students with feedback ad 7) Engage in peer critique • *Design Learning Task*: In groups, teachers design a learning task for argumentation that integrates one of the 7 teaching strategies. • *Video of 5th Grade Classroom*: Watch and discuss a video of a 5th grade classroom in which the teacher encourages classroom debate and student-to-student interactions.	• Read Chapters 4-6 of book (McNeill & Krajcik, 2012) • Try argument learning task with students • Bring 6 samples of student writing (2 stronger, 2 middle, 2 weaker) to Session 3
Session 3 3 ½ hours	• *Share Student Writing*: In groups, teachers shared their 6 samples of student writing as well as the challenges and successes. • *Full Class Discussion*: Share across the different groups lessons learned from the lesson as well as questions for future lessons. • *Analyze Classroom Transcripts:* Teachers analyzed transcripts of two classroom discussions around supporting argumentation. • *Presentation on Designing Assessment Tasks*: Facilitators present on how to design argument assessment tasks. • *Analyze Student Writing*. Teachers analyzed four samples of student writing using a specific rubric. Discuss the strengths and weaknesses of the student work and the rubric. • *Presentation on Providing Student Feedback.* Facilitators present strategies for providing students with effective feedback.	• None

The first workshop series targeted grade 5-8 teachers and was specifically developed in coordination with revising the draft version of the book (McNeill & Krajcik, 2012). Twenty-five teachers participated in this workshop and we met on September 26, October 29 and December 10 of 2009. Because of the success of the first workshop series, the science curriculum coordinator for the school district requested two more series one targeting high school teachers and one targeting elementary school teachers. Twenty high school teachers participated in the high school series and we met on December 5, 2009, January 7, 2010 and February 8, 2010. Twenty-five elementary school teachers participated in the elementary school series and we met on January 9, February 4 and March 15 of 2010.

Participants

The participants in this study included the seventy grade k-12 teachers that attended the workshops from one large urban district in New England. The urban school district serves primarily low-income (71% eligible to receive free or reduced lunch) students from minority backgrounds. The district enrolls approximately 56,000 students in grades K-12 with 42% African-American, 34% Hispanic, 14% White, and 9% Asian. More than 10,000 of the students (17%) are categorized as English Language Learners with the most common home language being Spanish. Teachers were recruited through the school district e-mail and online professional development website. Each of the three workshop series was capped at twenty-five participants. Both the grade 5-8 and elementary workshops were enrolled to capacity and the first twenty-five people to sign up were accepted. All interested high school teachers were accepted, because this workshop was not filled at capacity. All teachers who participated in the workshops received a copy of the draft version of the book and a stipend.

The teachers in the study included a wide range of experience and backgrounds (see Table 2).

Table 2: Teacher Demographics

Primary Subject Taught			Years Experience[a]		Highest Degree		
					Level	Subject	
						Education	Science
Science Specialist	Elementary	14	0 to 5	25	None	2	37
	Middle	12					
	High	19	6 to 10	15	Bachelors	2	25
General Classroom Teacher		14					
English/Language Arts		2	11 to 20	15	Masters	65	6
Special Education		4					
Other Resource Position		5	> 20	14	Doctoral	1	2
		70		69		70	70

[a] 1 teacher did not report their years of teaching experience

The teachers ranged in years of teaching experience from one year to forty-two years. Forty-five of the teachers were science teachers – either elementary science specialists, middle school science teachers or high school science teachers. In addition, the participants included, fourteen

elementary classroom teachers, two literacy and language arts teachers, four special education teachers and five other resource positions all of whom were interested in integrating more science and science writing in their classrooms. The majority of teachers, sixty-five of the seventy, had a masters degree in education. The majority of middle school and high school teachers had a science degree, either a bachelors or masters, while the majority of the elementary teachers did not have a degree in science.

Data Collection

Multiple data sources were collected to evaluate teachers' initial pedagogical content knowledge and beliefs as well as to determine whether or not their knowledge and beliefs changed as they participated in the workshop series. Data sources included: pre and post surveys, videotapes of the professional development workshops, artifacts produced by the teachers during the professional development, and learning tasks with associated student work designed by the teachers.

Pre and Post Survey. The pre and post survey included identical questions targeting teachers' beliefs and pedagogical content knowledge about scientific argumentation in both students writing and classroom discussions. We were interested in if the teachers successfully used the claim, evidence and reasoning framework to analyze student writing and talk for strengths and weaknesses. Furthermore, we were interested in what other strategies teachers used to analyze the work (e.g. focus on literacy or student and teacher interactions) and how those strategies changed over the course of the workshops. Appendix A includes the survey items analyzed.

Only teachers who completed the entirety of the pre and post-surveys were included in this analysis in order to be able to compare changes in ideas and beliefs across time. Some teachers did not complete the entire survey because they either chose not to respond to some of the survey questions or were unable to attend the last workshop. Consequently, this analysis includes 62 total teachers: 23 teachers from the grade 5-8 workshop, 17 teachers from the high school workshop and 22 teachers from the elementary workshop.

Videotapes and Teacher Artifacts from Workshops. We videotaped all nine sessions of the workshops (43.5 hours). Unfortunately, there were technical difficulties for Session 2 for the Grade 5-8 teachers and the video did not include audio. Consequently, we analyzed the video for eight workshop sessions. All videotapes were observed and segmented by the activity structure: presentation by facilitators, group activity, observation of video, and full class discussion. Since we were specifically interested in the understandings of the full group of teachers, we focused our analysis on the discussion. This included sections of the workshop in which the agenda originally included the facilitators presenting, but one of the teachers asked a question which led to a full group discussion that lasted one minute or longer. All discussions were transcribed resulting in the associated minutes of transcription from each session: Grade 5-8 Session 1 for 96 minutes, grade 5-8 Session 3 for 57 minutes, high school session 1 for 62 minutes, high school session 2 for 30 minutes, and high school session 3 for 53 minutes, elementary session 1 for 75 minutes, elementary session 2 for 30 minutes, and elementary session 3 for 44 minutes. Across the eight workshops, 7 hours and 27 minutes of the workshops were transcribed and analyzed. Furthermore, we collected all teacher artifacts produced during the workshop – such as the ideal 7^{th} grade argument written in Session 1 and the initial learning tasks designed in Session 2 and Session 3.

Learning Tasks and Samples of Student Writing. All teachers were asked to conduct two argumentation lessons with their students and to bring in six samples of student writing from each lesson. Although the majority of teachers did bring their learning tasks and samples of student work, some teachers chose not to participate. The following number of teachers brought in student work for the sessions: 18 for Grade 5-8 session 2, 16 for grade 5-8 session 3, 13 for high school session 2, 13 for high school session 3, 19 for elementary session 2 and 16 for elementary session 3. This work was collected and analyzed with a particular focus on the questions the teachers developed and the associated student writing.

Data Analysis

Initial coding began with an analysis of the teachers' pre and post surveys. The coding scheme for the survey was developed from the theoretical framework and iterative analyses of the data (Miles & Huberman, 1994). The goal of the coding scheme was to capture the characteristics of the discourse the teachers focused on when evaluating the student writing or classroom discussion. The coding scheme was informed by previous research focused on scientific argumentation (Jiménez-Aleixandre & Erduran, 2008; Osborne, Erduran & Simon, 2004; McNeill, 2009; Sampson & Clark, 2008; Zembal-Saul, 2009) as well as grounded in the teachers' own language when they discussed and wrote about these concepts (Strauss, 1987). Table 3 includes the codes for the student writing.

Table 3: Coding Scheme for Survey Items about Student Writing

Code	Description	Example
Claim	Discusses the inclusion of a claim or a conclusion that addresses the original question.	"The student neglected to make a claim."
Evidence	Discusses the inclusion of data or evidence in the response.	"The student cited data from the table."
Reasoning	Discusses the inclusion of researching that explains how or why the evidence supports the claim.	"The student explains how the density of the balls allows them to sink or float."
Conceptual	Discusses the quality of the conceptual understanding.	"The student correctly defined density."
Personal	Discusses the inclusion of personal or everyday experiences.	"It was good that the student included a personal experience."
Literary	Discusses the quality of the writing, such as discussing conventions, mechanics or organization.	"The writing was clear, concise and well organized."
Vague	Only used if no other codes applied. Vague or general comments about the writing.	"The explanation is clear. There could be more detail."

The coding scheme for the student writing included a focus on the framework introduced during the workshop – claim, evidence and reasoning – as well as other aspects that we found that the teachers focused on when discussing the writing – conceptual, personal and literary. The coding scheme for the teachers' analyses of the classroom discussions was similar (See Table 4).

Table 4: Coding Scheme for Survey Items about Student Talk

Code	Description	Example
Claim	Discusses the inclusion of a claim or a conclusion that addresses the original question.	"The claim made by the student was correct."
Evidence	Discusses the inclusion of data or evidence in the response.	"The students did not provide specific data."
Reasoning	Discusses the inclusion of researching that explains how or why the evidence supports the claim.	"The student neglected to explain the meaning of the data in terms of how it supports their conclusion."
Conceptual	Discusses the quality of the conceptual understanding.	"Students are off topic and do not appear to understand biodiversity."
Personal	Discusses the inclusion of personal or everyday experiences.	"The students are focusing on their personal experiences and not their data."
Teacher Directed	Discusses whether the discussion is overly teacher directed or includes an IRE structure.	"The discussion was too teacher directed."
Student Interaction	Discusses the level of student interaction such as whether the students were listening to and building off each other's ideas.	"There was student to student discussion."
Student Participation	Discusses the level of student participation such as whether multiple or only a few students participated.	"The discussion was limited to a couple of students."
Teacher Moves	Discusses the quality of specific teacher moves, questions or comments.	"When the teacher said "Great", students might have interpreted that as a judgment."
Vague	Only used if no other codes applied. Vague or general comments about the writing.	"The explanation is clear. There could be more detail."

In contrast to the student writing, the teachers did not talk about literary aspects (such as grammar and organization) so we did not include this code. However, the teachers were more likely to discuss the interactions of the classroom dynamics so the following codes were added – teacher directed, student interaction, student participation and teacher moves.

Independent raters coded the teacher surveys with two raters overlapping on 20% of the surveys. Inter-rater reliability was calculated by percent agreement. The percent agreement for the writing codes was 90%, and the classroom discussion codes were 89%. All disagreements were resolved through discussion. The coding of the surveys and subsequent data reduction resulted in the emergence of seven initial themes.

To challenge, refine, and enhance the validity of the themes developed from the survey, we next triangulated data from the workshop transcripts, teacher artifacts and learning tasks with associated samples of student writing. Two independent coders examined the multiple data sources. In examining the multiple data sources, we looked for confirming and disconfirming evidence for each of the themes to develop a more in depth understanding of the phenomenon

under study (Johnson, 1997). We recorded evidence in the form of quotes from the transcripts and examples from teacher artifacts, learning tasks and samples of student to challenge each theme. The two coders then compared evidence and suggestions for revision of each theme. Through this process we removed three themes because of lack of supporting evidence and contradictory evidence that challenged the original theme. Furthermore, we combined several other themes and refined the language of all of them resulting in four final themes presented in this paper. These four themes reflect the teachers' beliefs and understandings about scientific argumentation as they participated in the professional development sessions.

RESULTS

The analyses address the following research question: What are teachers' pedagogical content knowledge and beliefs for scientific argumentation while participating in professional development focused on this topic? Table 5 provides a summary of the four themes that emerged from the analysis. We next discuss each theme and provide evidence from the multiple data sources to support the themes.

Table 5: Themes around Teachers' Beliefs and PCK for Argumentation

Theme 1	In terms of student writing, teachers' understanding of evidence was strong and their understanding of claim and reasoning improved, but the application to classroom practice continued to be challenging, particularly in terms of reasoning.
Theme 2	Teachers exhibited limited PCK for how to apply argumentation to classroom discussions in terms of both the CER framework and dialogic interactions.
Theme 3	Elementary teachers frame argumentation in terms of connections to other disciplines, while high school teachers frame argumentation by discussing the science content or laboratory investigation.
Theme 4	Teachers found designing the question to be challenging but also important for providing students with the opportunity to justify their claims with evidence and reasoning.

Theme 1: In terms of student writing, teachers' understanding of evidence was strong and their understanding of claim and reasoning improved, but the application to classroom practice continued to be challenging, particularly in terms of reasoning.

In terms of teachers' ability to use the claim, evidence and reasoning framework to analyze student writing, the majority of teachers discussed the students' evidence from the beginning of the workshops while there was an increase in their discussion of both the claim and reasoning in the students' writing. Table 6 presents the results from the pre and post survey for the teachers' analysis of student writing. In the survey, the teachers were asked to analyze four samples of student writing. The results in Table 6 indicate what percentage of teachers included a discussion of that code for at least one of the four samples of student writing. For example, for claim 59.1% of the elementary teachers on the pre survey discussed claim in at least one of the

four samples of student writing. The highlighted cells include those codes that 70% or more of the teachers' responses were coded for on either the pre or post survey.

Table 6: Teachers' Analysis of Student Writing on Pre and Post Surveys

Code	Elementary (n=22)		Grade 5-8 (n=23)		High (n=17)		Total (n = 62)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Claim	59.1%	77.3%	73.9%	82.6%	58.8%	76.5%	64.5%	79.0%
Evidence	90.9%	90.9%	87.0%	95.7%	100.0%	100.0%	91.9%	95.2%
Reasoning	45.5%	81.8%	39.1%	91.3%	52.9%	82.4%	45.2%	85.5%
Conceptual	72.7%	50.0%	87.0%	73.9%	82.4%	64.7%	80.6%	62.9%
Personal	22.7%	27.3%	34.8%	34.8%	29.4%	11.8%	29.0%	25.8%
Literary	45.5%	13.6%	52.2%	21.7%	58.8%	29.4%	51.6%	21.0%
Vague	18.2%	31.8%	39.1%	13.0%	23.5%	17.6%	27.4%	21.0%

In terms of the pre survey, we were surprised by how large a percentage of teachers discussed the quality of the students' evidence in their writing. Across all of the teachers, 91.9% of them discussed students' evidence on the pre-survey with 100% of the high school teachers including a discussion of evidence. The teachers appeared to begin the workshop with an understanding of how to look for evidence in students' writing. In terms of the claim, we do see a change from 64.5% on the pre-survey to 79% of the teachers on the post survey discussing the quality of the students' claims in at least one of the four samples of writing.

The greatest change that we observed from pre to post was in the teachers' discussion of the students' reasoning in their written arguments with only 45.2% of the teachers discussing this on the pre survey compared to 85.5% on the post survey. In coding for reasoning, we looked for teachers to discuss whether or not the students' writing included a discussion of how or why the evidence supported the claim. For example, one teacher wrote on the post survey in analyzing Student D's writing, "There is a claim, a sufficient amount of evidence (fossils, stone types), and a well thought out *explanation for how this evidence could support the claim."* This teacher goes beyond just stating that the student provided a claim supported with evidence to articulate that the students also provided their reasoning for how the evidence supported the claim. This is different than on the pre survey when teachers tended to focus more on just the claim and evidence.

Based on the results of the post survey, participants in all three workshops left with an understanding of how to analyze students' writing in terms of the inclusion of claim, evidence and reasoning in that over 70% of the teachers discussed each of these components. Yet, when we examine the other data sources, we see that application to classroom practice continued to be a challenge at times, particularly in terms of the reasoning component. For example, in Workshop #1 the teachers worked in groups to design a learning task that utilized the claim, evidence and reasoning framework, which they would try with their students before Workshop 2. After working in groups, we discussed as a full class what they had learned from designing the learning tasks and what challenges arose in the process. A number of the teachers discussed challenges around differentiating evidence and reasoning or integrating reasoning. Table 7 includes sections of the discussion from the elementary workshop.

Table 7: Discussion of Challenges from Elementary Workshop #1

Sam	Oh I'm sorry, the reasoning portion is still confusing for me because you made the point that sometimes the reasoning is, has more scientific ideas and concepts and sometimes it doesn't. I understand that statement but I'm still trying to sort of process it. So if I'm still trying to process it then how can I explain it to my 3rd grade students, so that's what I am grappling with here.
Facilitator 1	And I think that goes back to the questions you ask. Right, like some questions are simpler and they don't require as much and some questions are more complex. SO maybe with your 3rd graders you actually, purposefully want to do some simpler questions that doesn't have to go into the science concepts as much versus when you get to fifth grade maybe then you are going to have some questions that are more complex.
Chevon	I was trying to grasp the reasoning and I looked at how they worded it and you basically answering it in a scientific concept. For instance, they have the water bottle cracked open, and their evidence and reasoning was because the outside temperature dropped down below 32 degrees Fahrenheit. The water froze, that's a scientific concept, and for me I'm saying as I try to teach it it'd be they'd do the evidence and we'd go back and look at each sentence and come up with a scientific concept for the reasoning, that's the way I'm internalizing it.
Linda	I just thought of something, something really weird just happened in my brain. My background knowledge has just changed. Because when I reason through something, my background knowledge comes from the activities, my experiments, my investigations so then the prior background knowledge that I had about water gets debunked or gets enriched so then my reasoning becomes richer and I can use the vocabulary, you know if I've got it, so then my reasoning becomes newly acquired background knowledge which will then support my thinking about these theories as I move through the grades. So my reasoning comes from that place, I can think about it, I can explain why it is, but it's because the way I understand it has changed. Does that make sense?
Facilitator 1	Yeah, I mean as the kids are doing investigations, collecting data, and making sense of that data, they should be doing this reasoning, they should be thinking through this and trying to figure out why it supports their claim. And getting them to write it down is hopefully helping them do that even more as well as figure out how to communicate it to someone else and justify what they are thinking. Questions. Do people have questions for me, for your colleagues, science dept. folks.
Kerry	We know that we did our reasoning wrong now, after all these presentations so the reasoning since it is very simple would it be, I know, I'm just throwing this out here - I know a lima bean changes with water, something like that because of the changes I observed like what would be the reasoning when a bean is soaked in water - changes are observed?

This section of the discussion begins by one teacher, Sam, saying that he is in fact still confused by the reasoning. Two other teachers, Chevon and Linda, then share how they have been trying to grasp reasoning. Finally, Kerry joins in to say that she know recognizes that in the learning task they designed the reasoning was in correct and provides another wording for the reasoning about the lima bean, which her colleagues continue to give her feedback in the next section of the transcript. This transcript illustrates that in the first workshop the teachers were grappling with reasoning and trying to develop a stronger understanding of it.

In the second workshop the teachers worked in groups to develop scientific argumentation writing prompts and teaching strategies to use with their students before the next workshop. In addition to designing the learning task, the teachers wrote an ideal example of a student written argument. At the grade 5-8 workshop, one group developed the following question – *How many different species are represented by the 4 types of zebras?* The reasoning included the following – *A species is a group of organisms that have similar characteristics and can mate to produce fertile offspring. Since Grant and Grevy can, they are 1 species. Since the others cannot interbreed they are each considered their own species.* This example illustrates how a student could apply their understanding of species to explain why their evidence supports their claim. This suggests the group had a strong understanding of what counted as appropriate scientific reasoning. This is in contrast to an example created by another group who asked the question – *Which school surface supports the most micro bacterial growth?* In their sample student response, they include the following as reasoning – *I collected multiple pieces of data to support my claim. I also identified the different microbes on the Internet*. This example of reasoning articulates what the students did, but does not focus on how or why the evidence supports the claim.

Finally, in the third workshop, the teachers appear to be more comfortable with reasoning and do not ask as many explicit questions about it. Yet when the teachers use a specific rubric to assess four samples of student work out of the three components, reasoning had the most variation in the scores that the teachers provided the students and the discussion included debate on the quality of the students' reasoning in their writing.

Across the three workshops as well as comparing the teachers' responses on the pre and post surveys, the teachers appeared to develop a stronger understanding of the framework. Reasoning was the most difficult component for them, yet they had an increased comfort with that as well. However, the application was still a challenge at times suggesting more support and practice would be important for developing greater expertise.

Theme 2: Teachers exhibited limited PCK for how to apply argumentation to classroom discussions in terms of both the CER framework and dialogic interactions.

While the teachers exhibited increased comfort in using the framework around science writing, the application of argumentation to classroom discussion continued to be a challenge. For example, in terms of teachers' critique of the transcripts of the classroom discussions on the pre and post surveys, different patterns emerged. Table 8 presents the results from this analysis. Again, the highlighted cells are those codes that 70% or more of the teachers' responses were coded for on either the pre or post survey.

Table 8 illustrates that the teachers were less likely to use the claim, evidence and reasoning framework as a tool to analyze the transcripts of classroom discussion compared to their analysis of student writing. Of the different components of the framework, teachers were most likely to talk about evidence, though this still is not as prevalent as in their discussion of student writing.

Besides a focus on structure, argumentation also includes dialogic interactions within the classroom. In coding the teachers' responses to the classroom discussions, two codes focused explicitly on these aspects – teacher directed and student interaction. The teacher directed code focused on the idea that one of the two transcripts exhibited a traditional IRE pattern of discourse while the student interaction code focused on the concept that students should be responding to their peers comments either by building on or refuting their ideas. Although the percentage of

teachers who discussed these codes did increase, the majority of the teachers who participated in the elementary and grade 5-8 workshops did not analyze the transcripts of classroom discussion from these perspectives on the post survey. Instead, the teachers were more likely to make general statements about teacher moves such as, "The teacher used encouraging words" rather than analyze the classroom discussion from an argumentation perspective. The high school teachers' responses on the post survey included a greater focus on argumentation in terms of the dialogic interactions, though their percentages were still lower than our overarching goals.

Table 8: Teachers' Analysis of Classroom Discussion on Pre and Post Surveys

Code	Elementary (n=22)		Grade 5-8 (n=23)		High (n=17)		Total (n=62)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Claim	27.3%	36.4%	17.4%	30.4%	11.8%	11.8%	19.4%	27.4%
Evidence	77.3%	72.7%	73.9%	52.2%	52.9%	70.6%	69.4%	64.5%
Reasoning	18.2%	18.2%	30.4%	26.1%	29.4%	23.5%	25.8%	22.6%
Conceptual	63.6%	50.0%	78.3%	73.9%	94.1%	76.5%	77.4%	66.1%
Personal	0.0%	0.0%	0.0%	0.0%	0.0%	5.9%	0.0%	1.6%
Teacher Directed	18.2%	0.0%	13.0%	30.4%	11.8%	58.8%	14.5%	27.4%
Student Interaction	22.7%	31.8%	43.5%	47.8%	41.2%	70.6%	35.5%	48.4%
Student Participation	36.4%	36.4%	26.1%	17.4%	29.4%	17.6%	30.6%	24.2%
Teacher Moves	68.2%	77.3%	73.9%	73.9%	58.8%	52.9%	67.7%	69.4%
Vague	81.8%	45.5%	43.5%	34.8%	52.9%	47.1%	59.7%	41.9%

Both Session 2 and Session 3 included sections that focused on integrating argumentation into classroom discussions including supporting student-to-student interactions in which the students built on the ideas of their peers. In examining the transcripts from these sections, much of the discussion was general and did not include specific talk around either the claim, evidence and reasoning structure or the student to student interactions. For example, in Session 3 the teachers analyzed two short transcripts of different teachers (Ms. Cruz and Mr. Reynolds) leading a discussion addressing the question – What characteristics of an instrument impact the pitch of an instrument? The two transcripts were designed so that Mr. Reynold's discussion included a more traditional IRE structure and focused on the content and Ms. Cruz's discussion focused on supporting claims with evidence and student-to-student interactions (see McNeill & Krajcik, 2012b). Table 9 includes a section of the discussion of the two transcripts from the Grade 5-8 classrooms. During this discussion the teachers spent a large section of the time discussing student misconceptions and how do you correct wrong answers.

Table 9: Discussion of Two Transcripts from Grade 5-8 Session 3.

Holly	I have a really hard time with this one when I am trying to support science and English- when do you correct the false assumptions – the wrong answers. Like she let this go – I don't know when to, if I even know the answer and I know they are wrong, when do you jump in – cut them off.
Ann	Well one thing I try to do is when the student says something – there was something in here, in this car thing where the student said, or it was one of the choices "car companies like FORD try to build nice cars". When a student will say something, I'll remind them

	that we are just talking about this experiment and how do you know that that's really true, is that something that you worked on in class or was that an experiment. Is that what you mean? To try to get them to focus on whatever they are saying has to be evidential or related to the topic with more precision.
Carol	Another taught trick that I've gone to trainings and I feel like the way that they, the teacher tries to use the thinking of other students to show to show the students, to help develop other students thinking and you correct.
Facilitator 2	I'm not sure I understand.
Carol	That if a student has you know does a problem and its wrong I think that the teacher is supposed to have other students comment on that work and show off different strategies and I think that is what happened in this classroom.
Facilitator 2	Bill
Bill	We noticed back here that in classroom number two Ms. Cruz never said right or good or great the way that Mr. Reynolds did up top. Even after the confusion so she waited for the other students to comment and give an alternative theory but if you left it there, there would still be confusion. So what she came and did was reminded of just the fact there – like she says "remember that pitch is how high or how low a sound is" so even though its not saying this student was right and this student was wrong so there's no validation or humiliation of any sort. Its just remember this is the facts and the student who was wrong is like "oh that's right, I remember now". I think its important that they understand what the fact is when they leave the conversation, this classroom #2 does it in a way that is really conducive to keeping the emotionality of it away from it.

The focus of this conversation was not on argumentation. The teachers did not tend to focus on either supporting claims with evidence or the nature of the student interactions. Rather they focused on other aspects of the transcripts they found interesting. The teachers exhibited a limited understanding of how to apply argumentation to classroom discussions.

In the high school workshops, the discussions were a little more focused on the argumentation qualities of the discussions however the teachers did not appear to completely embrace the idea of integrating argumentation into classroom discussion. For example, at the end of Session 2 the teachers watched a video of a 5th grade classroom in which the students are debating the quality of different evidence and engaging in student to student interaction. After watching the video, the facilitator asked the teachers for their impression of the video. The transcript in Table 10 is from the beginning of the discussion.

Table 10: Discussion of Using Argumentation in Discussion from High School Session 2

Facilitator 1	So what do you think?
Shannon	I think it would work.
Facilitator 1	You do.
Shannon	I think the reason I wouldn't use it is because I would have to develop all those things…I mean really its just a time constraint to develop…its just another piece and I don't have time to do it…but I think it would work. But also its another lesson that I have to add into the lesson that I already have to do, it's like a scaffold, for a scaffold, for a scaffold. It's like a two day lesson, you know, becomes four. But I really think its great and if it wasn't like…if you had your own class but there was no, if it was just a class, just a

	science class, teach a science class I think it would be an awesome strategy that I would use (Inaudible)
Tina	I think it's really good too and I agree though it's a lot more preparation and time spent but I really like it because I think it gives both examples and non-examples. So you can focus and say, but, Okay so you didn't choose this – why – so you're hitting both what's good and what's not good so they get both of that in that format.
Facilitator 1	What about in terms of like getting your to talk, to each other, listen to each other? Carla.
Carla	This is a culture issue in my class that I know in January I'm probably not going to change but I'm fairly certain how it goes in my class is a kid will present the wrong option and the really loud always right kids will scream them down about how stupid they are – and I know that has nothing to do with the activity its just that I didn't do a good enough job of establishing appropriate communication in my class at the beginning of the year. And so the right answer I know would come out in my class and the right reasoning will be stated, but whether or not those other students can say it articulate enough or non judgmentally enough, so it was understood by the other students is where I think it would fall apart.
Jeremy	I thought it always produced good and productive discussions if you present to the students two or more alternatives for them to discuss and maybe even I've done in seminars, papers presenting opposite points, you know published papers that present opposite points of view for students to debate and that really gets them going. You know they read the first paper and of course this makes sense and then they read the second paper saying the first one doesn't make sense and then they have to stop back and think and it really uh gets them going its very productive that way.
Facilitator 1	Yeah.
Tina	I was just thinking in response to what you said, maybe like either if you had them think on their own and then work with one other person and then do the whole group maybe you might eliminate some of the like yelling out and that might give the chance for kids who maybe didn't get the answer that you wanted to sort of see why you know by talking to one kid.

During the discussion, Shannon expresses concern about time constraints both for developing the lessons and for engaging her students in argumentation. Carla is concerned about the culture of her classroom and that the students will end up screaming with each other. Both Tina and Jeremy are more positive; however, overall the high school teachers had concerns about integrating argumentation into their classrooms.

In both the data from the surveys and the transcripts from the discussion during the sessions the teachers exhibited a limited understanding of how to apply argumentation to classroom discussions. These results suggest that the professional development did not provide them with enough support around discussions. Furthermore, in reflecting on the agenda (See Table 1), we realized we spent considerable more time focused on argumentation writing compared to argumentation talk. We discuss this idea in more depth in the discussion.

Theme 3: Elementary teachers frame argumentation in terms of connections to other disciplines, while high school teachers frame argumentation by discussing the science content or laboratory investigation.

In examining the nature of the discussion during the three workshop, the artifacts produced during the workshops and the learning tasks and samples of student writing that the teachers brought to the workshops, we observed differences in how the teachers framed argumentation. Specifically, the elementary teachers were more likely to connect argumentation in science to similar practices in other disciplines such as language arts and mathematics. On the other hand high school teachers were more likely to focus on argumentation as a way to support the development of science content or a way to make sense of and communicate the results from a laboratory investigation. The teachers who participated in the grade 5-8 workshop fell in the middle framing argumentation in both ways.

During the first elementary workshop, the teachers frequently made connections to other content areas, especially language arts. For example, Table 11 includes an excerpt from a discussion of a video of a 7th grade teacher who is introducing the claim, evidence and reasoning framework to her classroom. In discussing how the teacher introduced the term claim, the elementary teachers made connections to ELA.

Table 11: Discussion of ELA in Elementary Session 1

Joy	In ELA we teach them to expand their writing- expand, expand, expand. So that's probably what they are used to most, so they write more.
Facilitator 1	Yeah. Molly.
Molly	I think they need to understand how to write in a different genre because a lot of them are used to writing in personal narratives and they're starting off with different kinds of leads, and going back and telling the whole entire story. Where this is something totally different that needs to be explicitly taught that in different genres we write in different ways.

Frequently throughout the first workshop the teachers made connections to the other disciplines, particularly language arts. During the second and third workshops, these connections continued to be made, though not quite as frequently. For example, in the third workshop one of the teachers brought in as their sample of student argumentation writing a math writing prompt that stated: *Bob stated he ate more pizza than Jane. Jane disagreed saying that she had eaten more pizza. Bob ate 5/8 of a pizza and Jane ate ¾ of a pizza. Who ate more pizza?* A number of the teachers who participated in the elementary workshops taught all of the content areas, not just science, and were interested in thinking about the connections to the other disciplines.

In contrast, the high school teachers never connected to the other disciplines in any of the three workshops. Instead, the teachers were much more likely to talk extensively about the science content or potential misconceptions the students might have about the content. For example, in the first workshop the teachers analyzed four samples of student writing in which the students wrote an argument about whether or not a new substance was formed during a chemical reaction. In critiquing the students' writing, the teachers specifically talked about the science content in the answers (see Table 12).

Table 12: Discussion of Content in High School Session 1

Marie	They brought in the science content of properties are the same unless the substance changes and then says, "see how my evidence says properties changes" so I know there's a new substance. So linking that, their prior knowledge of properties and substances.
Facilitator 2	Um…I think they are also trying to make the connection for multiple pieces of evidence. So trying to explain why each piece of data supports the claim. Um, I don't think that the student gets at every piece of data that is stated, I didn't look and double check, but I think they are trying in that regard, to link more than one, the reason for more than one piece of data, which is a pretty advanced concept.
Bob	And also there's a lot of you know, this little piece of evidence is an example of a big phenomenon and this one is an example of a big phenomenon and so forth.
Facilitator 2	mmmhmmm
Christopher	So, so, so they are clearly associating what is the definition for a chemical change when they are answering…. they know what a chemical change is and they are giving specific instances of the different properties that you would look for in a chemical change. So unlike the people we've looked at so far, this student clearly knows what is a chemical change and knows the details that characterizes a chemical change.

Furthermore, the writing prompts the high school teachers developed were more likely to be focused on the content or the results of the investigation and never included other disciplines like the elementary math argumentation writing prompt previously mentioned.

Theme 4: Teachers found designing the question to be challenging but also important for providing students with the opportunity to justify their claims with evidence and reasoning.

Across all three workshop series, during the discussions the teachers brought up the idea that designing the question for an argumentation lesson was challenging. For example, in the beginning of the grade 5-8 Session 3 workshop, one of the teachers shared that a challenge that came up with his lesson was the wording of the question. He said:

> *The question is like crucial and even if you try to tweak the question you are in trouble. Because if you start in one period and you realize what you did is not what you are looking for – the next period you try to tweak it – you realize aw shucks now I'm in some other space I'm not even sure I want to be in. If you are fortunate to be in a situation where you have 2 classes or more that get the same lesson, sometime what you start with is definitely not what you are looking for so you're like "aw that's not what I'm really looking for". Once they really value and respect you they have to answer it to the best of their ability but the question is really important, how you frame the question.*

Furthermore, when analyzing the lesson tasks and samples of student writing that the teachers brought to the workshops, we found that many of the questions did not provide students with an opportunity to justify the claims they made with evidence. Specifically, of the 95 questions with samples of student work that teachers brought into the different workshops, only 49 of them (52%) were high quality argumentation questions in that there was clear and explicit data that the students could use to justify the claims that they made. Other questions focused just on the science content or asked students to make predictions without providing them with any data to inform their predictions. In other cases, there was potential data that the students could use, but

the wording of the question was vague and it was unclear that the students were suppose to use specific evidence to back up there claims instead of just relying on content knowledge.

DISCUSSION

Overall, we found that the professional development workshops were successful in supporting teachers' development of pedagogical content knowledge for argumentation in terms of science writing. Over 70% of the teachers were able to successfully use the claim, evidence and reasoning framework to analyze student writing on the post-survey. This suggests that the framework did provide teachers with a valuable tool to assess and provide feedback on the quality of student writing. However, while teachers developed a stronger understanding, they still had challenges in applying what they had learned to classroom practice, particularly in terms of the reasoning component. Previous research focusing on student learning suggests that students struggle with the reasoning component in which they explain how or why their evidence supports their claim (Bell & Linn, 2000; McNeill, Lizotte, Krajcik & Marx, 2006). Interestingly, this component also appeared to be the most challenging for teachers to develop an understanding of and apply to the design of their own lessons focused on supporting argumentation. Although these changes are not large, they suggest that engaging teachers in professional development can alter their overarching beliefs about science teaching. Previous research suggests that teacher beliefs are very resistant to change (Jones & Carter, 2007). Consequently, any change after only 14 ½ hours of professional development can be seen as successful. Future research should examine teachers' beliefs over an even longer period of time to see if more sustained professional development can have a larger impact.

In terms of analyzing the classroom discussion, there was not a change in the majority of the teachers' use of the framework. Yet argumentation is essential not just for student writing, but also for developing a classroom culture in which students considering and countering their opponents' arguments (Kuhn, in press). The focus on the professional development workshops was much more on writing than on classroom discussion. Consequently, the lack of change in teachers' pedagogical content knowledge for classroom discourse may be a reflection of this limitation. In future workshops, we plan to include more of a focus on talk as well as writing since the integration of the framework into classroom discussion can also have a positive impact on student writing (McNeill, 2009).

One unique aspect of this work is that we conducted the same professional development series with three different groups of teachers – elementary, middle and high school. The teachers in these three groups had different backgrounds in that the elementary teachers were more likely to teach other subject areas and were less likely to have a degree in science. In contrast, the high school teachers were more likely to have science degrees and less likely to teach other topics. Consequently, it is not surprising that these teachers framed argumentation in different ways both during the discussions in the professional development and in the work they completed with their students. The elementary teachers were more likely to make connections to other disciplines while the high school teachers were more likely to focus on the science content.

Finally, in this professional development we asked teachers to integrate argumentation into their existing science curriculum to provide their students with an opportunity to justify the claims they make with evidence. The teachers identified one of the challenges of this process to be the development of appropriate questions. Furthermore, in analyzing the teachers' questions we found that many of them did not provide students with the opportunity to use evidence to

support a claim. This suggests that one area of future work would be to develop argumentation questions that teachers can integrate into their existing science curriculum as well as associated resources to evaluate students' arguments and to consider next steps in their instruction. Although argumentation is an essential goal for science classrooms (Duschl, et. al., 2007), it is also challenging. Teachers need more resources and tools to help them better integrate argumentation into their classroom practice.

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Teacher Pre and Post Survey

Classroom Example #1

Below is an assignment that Ms. Ginger gave to her students. Read through the assignment and then read the two examples of student writing for this task.

Sam conducted an investigation to determine whether different balls would sink or float in water. Below is a table with some data he collected about the water, the ping pong ball, the golf ball and the bowling ball.

	Mass	Volume	Density
Water	20,000.00 g	20,000.00 cm^3	1.00 g/cm^3
Ping Pong Ball	2.70 g	33.51 cm^3	0.08 g/cm^3
Golf Ball	45.93 g	40.49 cm^3	1.13 g/cm^3
Bowling Ball	4989.52 g	5454.52 cm^3	0.92 g/cm^3

Which of the balls do you think will sink? Explain why you think the ball or balls will sink.

Student A

The golf ball and the bowling ball will sink. Density determines whether or not an object will float or sink. Something with a high density has a lot of mass in a particular volume – it is very packed. So if an object has a density higher than water (1.00 g/cm^3), then it will sink. The golf ball has a density of 1.13 g/cm^3 so it will sink. In the table, the bowling ball density is low, but that must be wrong because bowling balls are really heavy. The mass of the bowling ball is 4989.52 g. I have also dropped a bowling ball before and it made a loud sound. So I know that the bowling ball will sink in water too.

Student B

The golf ball will sink. The density of the water is 1.00 g/cm^3 and the density of the golf ball is 1.13 g/cm^3. The ping pong ball and bowling ball will float, because there densities are 0.08 g/cm^3 and 0.92 g/cm^3.

1. For each student, circle how you would describe the quality of his or her writing (1 = poor and 6 = excellent). Explain your rationale for this choice.

   Student A

   Quality: *1* *2* *3* *4* *5* *6*

   Rationale:

   Student B

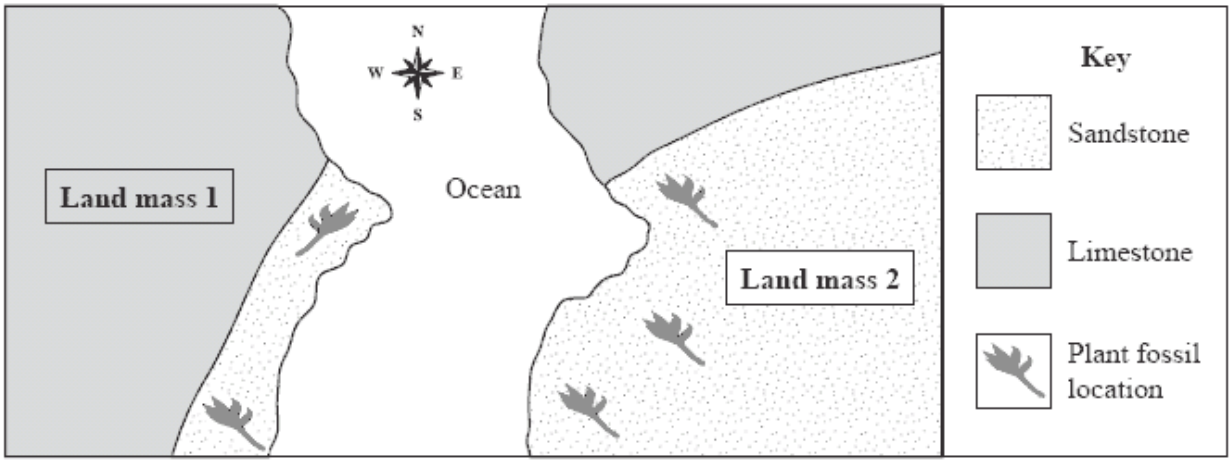
   Quality: *1* *2* *3* *4* *5* *6*

   Rationale:

Classroom Example #2

Below is an assignment that Mr. Morris gave to his students. Read through the assignment and then read the two examples of student writing for this task.

The diagram below shows two land masses separated by an ocean.



Do you think these two land masses have always been in the same location or do you think they were once in a different location? Explain why you came to this conclusion.

Student C

The two land masses have not always been in the same location. They were once connected to each other without an ocean in between them. The land masses moved because of plate tectonics, which is the idea that the earth's crust is made of many large plates that slowly move over time on top of the hotter more liquid mantle.

Student D

The two land masses have always been in the same place. The diagram shows that the two land masses are made of similar stone. They are both made of sandstone and limestone. The two land masses also have similar plant fossils. That is why I think they were once connected and the ocean did not use to be there. Some type of earth process caused the water in the ocean to cover the land between the two land masses. There was probably a glacier or flood that brought the water for the ocean. If the water was removed from the ocean, the land underneath would also be made of sandstone and limestone as well as have similar plant fossils. The two land masses have not moved, but they were clearly once connected.

2. For each student, circle how you would describe the quality of his or her writing (1 = poor and 6 = excellent). Explain your rationale for this choice.

   Student C

   Quality: *1* *2* *3* *4* *5* *6*

   Rationale:

   Student D

   Quality: *1* *2* *3* *4* *5* *6*

   Rationale:

Classroom Example #3

Below is a transcript from a classroom that just completed an investigation exploring biodiversity in their schoolyard. The transcript shows the teacher, Mr. Lewis, beginning a discussion about the students' conclusions for the investigation.

Mr. Lewis: I want you to share your ideas about the question we have been investigating – Is the biodiversity in our schoolyard high or low? And I don't just want you to say yes or no. Rather I want you to tell me why you think the biodiversity is high or low. Chris – what do you think?

Chris: I think that our schoolyard has a high biodiversity, because my partner and I collected data that there are 20 different species in our schoolyard.

Mr. Lewis: Ok. That is great. So you found data that there are 20 different species. Kayla, what did you find?

Kayla: We found that there were a lot of some species, like squirrels, but for most species there were only one or two animals, like there was only one song sparrow.

Mr. Lewis: Interesting. So what do you think that means in terms of our research question? Does that suggest that the biodiversity is high or low?

Kayla: We think the biodiversity is in the middle. It would be higher if there were lots of all of the different species.

Mr. Lewis: Great. What did other groups find?

6. Circle how you would describe the quality of this discussion (1 = poor and 6 = excellent).

   Quality: *1* *2* *3* *4* *5* *6*

7. What are the strengths of the discussion?

8. What are the weaknesses of the discussion?

Classroom Example #4

Below is a transcript from a classroom that just completed an investigation exploring biodiversity in their schoolyard. The transcript shows the teacher, Ms. Jackson, beginning a discussion about the students' conclusions for the investigation.

Ms. Jackson:	We have been investigating the question - Is the biodiversity in our schoolyard high or low? Based on all of your investigations, we now need to answer this question as a class. What are some of your ideas?
Shelly:	I think the biodiversity is low, because we live in a city and it is really dirty.
Will:	I agree with what Shelly said. I think the biodiversity is low. There is always trash in our schoolyard even though I try to pick it up and I tell other people to pick up their trash.
Dan:	I disagree. Just because we are in a city doesn't mean there are not any animals. And it really is not that dirty. It is much cleaner out there now then it was at the beginning of the school year.
Maria:	But we should make it even cleaner. Maybe we can get the whole school to clean it up. And we could even turn part of the schoolyard into a garden or something.
Ms. Jackson:	I am hearing lots of interesting ideas. Do the rest of you agree or disagree with these ideas?
Anna:	I agree with Shelly and Will. I think the biodiversity is low, but like Maria said we could make it better.

9. Circle how you would describe the quality of this discussion (1 = poor and 6 = excellent).

   Quality: *1* *2* *3* *4* *5* *6*

10. What are the strengths of the discussion?

11. What are the weaknesses of the discussion?