

*Research Article***Science Teachers and Scientific Argumentation:
Trends in Views and Practice**Victor Sampson¹ and Margaret R. Blanchard²¹*School of Teacher Education and FSU-Teach, College of Education, The Florida State University, Tallahassee, Florida*²*Department of Science, Technology, Engineering, and Mathematics Education, North Carolina State University, Campus Box 7801, Raleigh, North Carolina 27695-7801**Received 12 August 2010; Accepted 2 August 2012*

Abstract: Current research indicates that student engagement in scientific argumentation can foster a better understanding of the concepts and the processes of science. Yet opportunities for students to participate in authentic argumentation inside the science classroom are rare. There also is little known about science teachers' understandings of argumentation, their ability to participate in this complex practice, or their views about using argumentation as part of the teaching and learning of science. In this study, the researchers used a cognitive appraisal interview to examine how 30 secondary science teachers evaluate alternative explanations, generate an argument to support a specific explanation, and investigate their views about engaging students in argumentation. The analysis of the teachers' comments and actions during the interview indicates that these teachers relied primarily on their prior content knowledge to evaluate the validity of an explanation rather than using available data. Although some of the teachers included data and reasoning in their arguments, most of the teachers crafted an argument that simply expanded on a chosen explanation but provided no real support for it. The teachers also mentioned multiple barriers to the integration of argumentation into the teaching and learning of science, primarily related to their perceptions of students' ability levels, even though all of these teachers viewed argumentation as a way to help students understand science. © 2012 Wiley Periodicals, Inc. *J Res Sci Teach* 49: 1122–1148, 2012

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One way to help improve the teaching and learning of science is to promote and support student engagement in scientific argumentation (Duschl, Schweingruber, & Shouse, 2007). The available literature, however, indicates that opportunities for students to participate in authentic scientific argumentation inside the classroom are rare (Roth et al., 2006; Weiss, Banilower, McMahon, & Smith, 2001). This is due to the fact that most teachers lack the pedagogical knowledge necessary to design lessons that foster student engagement in scientific argumentation and have limited resources to assist them (Simon, Erduran, & Osborne, 2006). Given these barriers, a great deal of effort has focused on the development of new curricula (McNeill et al., 2003; Stewart, Cartier, & Passmore, 2005), technology-enhanced

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learning environments (Clark & Sampson, 2006; Sandoval & Reiser, 2004), and instructional strategies (Osborne, Erduran, & Simon, 2004; Sampson, Grooms, & Walker, 2011) that science teachers can use to engage students in scientific argumentation.

The implementation of any of these materials or strategies, however, will require skilled teachers who understand scientific argumentation and value this type of activity as a way to promote meaningful learning in science (McNeill, Lizotte, Krajcik, & Marx, 2006; Simon et al., 2006). Therefore, as is the case for all science education reform efforts (e.g., Blanchard et al., 2010; Woodbury & Gess-Newsome, 2002), the successful integration of scientific argumentation into the teaching and learning of science will place new expectations on teachers. Classroom teachers, for example, will be expected to understand the nuances of scientific argumentation so they can teach students about it (McNeill & Krajcik, 2008; Simon et al., 2006) and will need to be able to establish classroom norms that are more conducive to argumentation (Berland & Reiser, 2009; Osborne et al., 2004). Teachers also will need to understand the benefit of argumentation as a way promote student learning for them to be willing to use these unfamiliar strategies inside the classroom (Feldman, 2000). Because we have little understanding of what teachers know about scientific argumentation or the extent to which they value its role in the teaching and learning of science, this study was designed to help address this issue.

Theoretical Foundation

Argumentation and Arguments in Science

This study builds on the work of Duschl and Osborne (2002) and Driver, Newton, & Osborne (2000). Duschl and Osborne (2002) describe scientific argumentation as an important scientific practice that is used “to solve problems and advance knowledge” (p. 41). Driver et al. (2000) view scientific argumentation “as an *individual* activity, through thinking and writing, or as a *social* activity taking place within a group” (p. 291, emphasis in the original). We therefore define argumentation in science as a knowledge building and validating practice in which individuals attempt to establish or validate a conclusion, explanation, conjecture, or other claim on the basis of reasons (Sampson & Clark, 2009, 2011). Figure 1 depicts the model we use to describe the components of an argument in science (Sampson et al., 2011). In this model, a claim is supported by evidence and the evidence is then justified with a rationale. The evidence component of the argument includes measurements, observations, or findings from other studies that have been collected, analyzed, and then interpreted by the author. The rationale component of the argument, in contrast, justifies the individual’s choice of evidence and provides a link between the claim and the evidence used to support it.

This model highlights criteria that are often used by scientists in order to evaluate the quality of an argument. Empirical criteria include standards such as how well the claim fits with all the available evidence, the adequacy of the evidence included in the argument, and the overall quality of the evidence. Theoretical criteria, in contrast, refer to standards that are more conceptual in nature. These include judgments about the usefulness of the claim, its adequacy, and how consistent the claim is with other theories, laws, or models in the field. Finally, analytical criteria are used to evaluate the overall quality of the line of reasoning (e.g., correlational, hypothetical-deductive) and to determine if the analysis and interpretation of the data was sound. What counts as quality within these different categories varies from discipline to discipline, depending on the types of phenomena investigated, what counts as an accepted mode of inquiry, and the theory-laden nature of scientific work (Chinn & Malhotra, 2002; Passmore & Stewart, 2002; Sandoval, 2005). The nature of the components that make

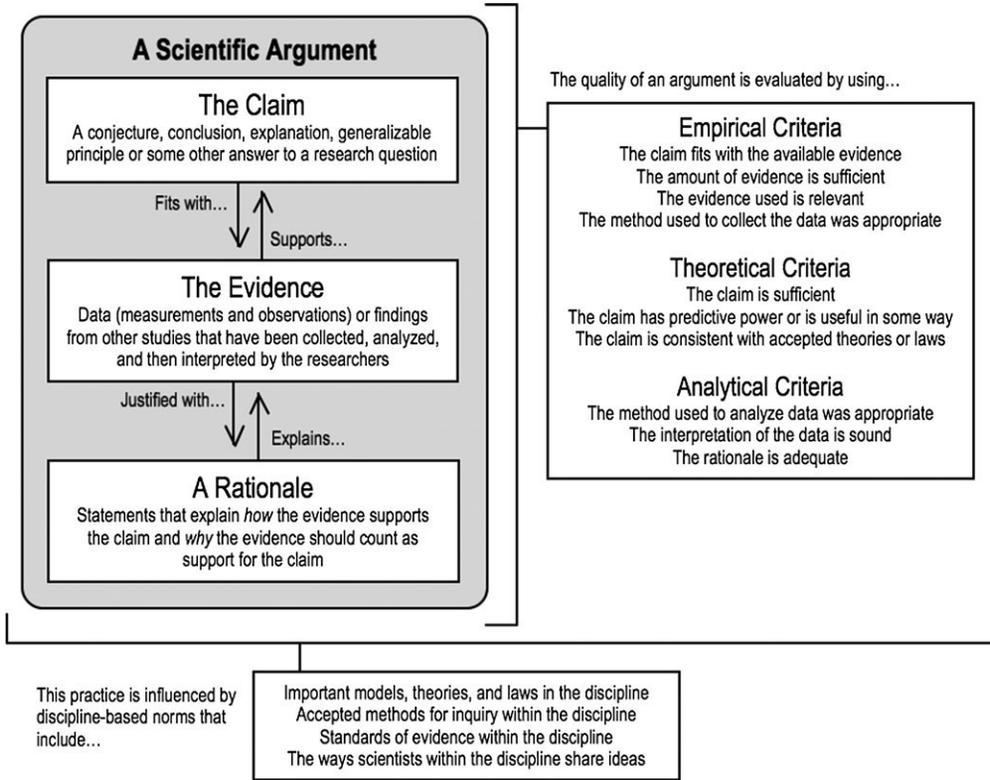


Figure 1. A scientific argument and some criteria that can be used to evaluate the quality of a scientific argument.

up a scientific argument and what counts as quality, as a result, depends on the discipline, field, and even research area.

Argumentation and Science Education

A number of science educators have argued that the ultimate aim of the current reform movement in science education should be to help students become more proficient in science (Duschl et al., 2007; National Research Council, 2008). This perspective contends that scientific proficiency requires teachers to equip students with the knowledge and abilities they need to be able to participate in the various practices of science and understand how these practices shape the nature of scientific knowledge. One important practice that helps shape the nature of scientific knowledge, as noted earlier, is argumentation. Yet, if students are to be able to participate in scientific argumentation, then the pattern of classroom instruction must shift (Berland & McNeill, 2010; Osborne et al., 2004). Teachers cannot simply focus on explaining the theories, laws, models, and unifying concepts of the various disciplines if they want to help student learn how to participate in scientific argumentation; teachers must also focus on ‘how scientists know’ what they know. Therefore, teachers need to provide structured opportunities for students to practice participating in scientific argumentation so students have a chance to learn *from* (e.g., important theories, laws, models, or concepts) and *about* (e.g., how scientific argumentation is different from everyday forms of argumentation) scientific argumentation.

The available literature, however, suggests that most science teachers do not engage students in scientific argumentation inside the classroom (Weiss et al., 2001). The two explanations that are most often found in the literature are teachers' limited pedagogical knowledge and the shortage of instructional resources (Simon et al., 2006). However, there might be other obstacles that make the integration of argumentation into the teaching and learning of science hard for classroom teachers. Some teachers, for example, might not encourage students to evaluate alternative explanations or develop evidence-based arguments because they define science as a body of knowledge to learn (Carlsen, 1991) or because they view argumentation as an ineffective way for students to learn content. It might also be difficult for teachers to promote argumentation inside the classroom if they do not know how to participate in scientific argumentation or understand how scientific argumentation differs from the nature of the argumentation that takes place in other contexts. These types of explanations seem reasonable given the vast amount of literature that suggests that science teachers tend to focus on explaining concepts (Weiss et al., 2001) and often have an inadequate understanding of the nature of science (Abd-El-Khalick & Lederman, 2000) or the nature of scientific inquiry (Windschitl, Thompson, & Braaten, 2008). Science educators, therefore, need to learn more about what practicing teachers know about scientific argumentation and what they think about the current proposals to integrate argumentation into the teaching and learning of science.

Science Teachers and Other Reform Movements in Science Education

Understanding what teachers know about argumentation and their views about the role of argumentation in science education is important because the extent to which a new curriculum, instructional strategy, or technology-enhanced learning environment is actually used depends largely on what teachers know, what they value, and how they decide to use it. Current research indicates that teachers play a fundamental role in any reform effort because curriculum implementation and classroom instruction are often shaped by teachers (Blanchard, Southerland, & Granger, 2009; Lotter, Harwood, & Bonner, 2007). Haney, Lumpe, Czerniak, and Egan (2002), describe classroom teachers as the "change agents" in the reform process because they are the ones who determine and shape the nature of classroom instruction. Teachers tend to privilege and use the instructional strategies that they think will work more often than the strategies that they see as ineffective (Keys & Bryan, 2001). Science education researchers need to learn more about teachers' knowledge and views of the use of argumentation. Without this, current efforts to integrate more argumentation into science education will, in all likelihood, be restricted to the pages of policy documents, curriculum guides, and academic journals.

Review of the Literature and Research Questions

There is a great deal of research that focuses on how students participate in argumentation (e.g., Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Osborne et al., 2004; Sampson & Clark, 2011), evaluate explanations (e.g., Berland & Reiser, 2009; Sampson & Clark, 2009; Sandoval, 2003), and craft arguments (e.g., McNeill et al., 2006; Sandoval & Millwood, 2005). Unfortunately, there are relatively few studies that have examined how teachers participate in argumentation, evaluate explanations, or craft arguments. Additionally, little is known about the relationship between teacher thinking and what goes on inside the classroom when teachers attempt to promote and support student participation in scientific argumentation. The literature that is available, however, suggests that what teachers know about argumentation can influence the nature of classroom activities and what students learn.

The work of Simon et al. (2006), for example, indicates that teachers need to understand what does and does not count as an argument in science and how to evaluate scientific arguments in order to help students learn how participate in argumentation in a manner that reflects the norms and goals of science. They also found that the emphasis a teacher places on different aspects of an argument (e.g., the nature of the explanation or the quality or type of justification) depends on what a teacher values in an argument as well as their goals for student learning. Other researchers have found that teachers shape the nature of the argumentation that takes place within the classroom and what students learn from this type of activity. A study conducted by Kelly and Chen (1999) suggests that the way a teacher frames a task for his or her students influences the nature of the arguments that students create. Similarly, a study conducted by McNeill and Krajcik (2008) indicates that students tend to improve their ability to craft a high quality argument when their teacher provides an explicit rationale for the importance of argumentation in science and defines the different structural components of a scientific argument in an appropriate manner. Research conducted by McNeill and Pimentel (2010) also indicates that a teacher's use of open-ended questions may play a key role in supporting students in argumentation and encouraging dialogic interactions between students. Although the literature in this area is limited, it is clear that teachers influence how students evaluate explanations, craft arguments, and participate in argumentation. Teachers also shape what students learn.

This literature, when taken together, illustrates how important it is for teachers to have a strong understanding of scientific argumentation and arguments. This literature also suggests that a teacher's view about the role of argumentation in science and what a teacher values are important influences on the nature of argumentation that is implemented. Simon et al. (2006), as a result, recommend that "the focus of professional development should be on teachers' existing understanding of the importance of evidence and argument in science and on their implicit goals of teaching and learning science" (p. 256). We assert that devising appropriate professional development for practicing science teachers will require a better understanding of their skills, knowledge, and views about using scientific argumentation inside the classroom. This study, as a result, was designed to develop tentative answers to the following research questions:

1. How do practicing science teachers evaluate the validity or acceptability of alternative explanations for a natural phenomenon?
2. What are the characteristics of the arguments practicing science teachers generate in order to support a chosen explanation for a natural phenomenon?
3. What are practicing teachers' views about the integration of scientific argumentation into the teaching and learning of science?
4. Do practicing teachers evaluate explanations, craft arguments, and view argumentation differently based on background and teaching context?

Method

Given the exploratory, descriptive nature of the research questions, we used interviews and qualitative data analysis techniques to better understand the argumentation strategies teachers use and to capture their views about engaging their students in argumentation.

Context

To increase the likelihood of identifying the different ways classroom teachers evaluate explanations and craft arguments and their views about engaging students in argumentation,

we interviewed a diverse set of teachers. The study participants were recruited from a population of secondary school science teachers that work in a large public school district located in the southeastern United States. This school district serves a diverse group of students with a total of 10 middle schools and five high schools. According to the public accountability report released by the district in 2008, a total of 30,475 students were enrolled in the district during the 2007–2008 school year: 48.8% of these students were White, 41.6% were Black, 3.2% were Hispanic, and 2.9% were Asian. Approximately 32.2% of the students were classified as economically disadvantaged, 17.2% were classified as disabled, and 1.4% of the students were classified as an English language learner. The 10 middle schools in the district range in size from 620 students to 1,240 students and the five high schools range in size from 1,389 students to 1,798 students. Minority students range from 11% to 82% of the student population in the middle schools and from 9% to 74% of the student population in the high schools. Economically disadvantaged students range from 5% to 76% of the student population in the middle school and from 6% to 58% of the student population in the high schools.

Participants

The 30 teachers participating in the study were purposefully selected to represent the wide range of teaching contexts found within the district and to reflect the various levels of teacher preparation and experience. This maximum variation sample included teachers with a range of experience (1–26 years), a variety of science and non-science undergraduate majors, a mix of advanced degrees, and an assortment of science discipline areas (biology, chemistry, physics, and integrated science). In addition, at least two teachers from every middle school and high school in the district were included in the sample. Table 1 presents a summary of some pertinent demographic information for the sample of teachers.

Data Collection

We used a *cognitive appraisal interview* (or CAI, see Silverman, 2010, for a detailed discussion of the method) to examine how the participants in this study engage in two important practices associated with argumentation and to elicit their views about integrating argumentation into the teaching and learning of science. During a CAI, the interviewer first provides the subject with a problem to solve or a task to complete. The interviewer then provides the subject with time to complete the activity. Afterwards, the interviewer asks the subject to describe his or her reasoning or the strategies he or she used in order to solve the problem or complete the task. A CAI gives the subject a chance to reflect on and discuss what he or she just did, which according to Henderson, Podd, Smith, and Varela-Alvarez (1995), tends to yield more useful information about how people think than a survey or a test. The CAI stems from the tradition of the cognitive interview that was first developed in educational psychology (see Willis, 2005). However, unlike a cognitive interview, which relies on “think aloud” or “verbal probing” techniques to examine an individual’s thinking during a task, the CAI is designed to encourage participants to offer an appraisal of their thinking after they have had a chance to complete a task or solve a problem.

The CAI we developed for this study included three distinct stages (see Table 2). We designed the first stage of the interview to examine how the participants in the study evaluate alternative explanations for a natural phenomenon. The second stage was designed to provide insight into the diverse ways teachers craft arguments in science. The intent of the third stage was to elicit teachers’ views about current proposals that call for a more explicit focus on scientific argumentation as part of the teaching and learning of science. The interviewer (first author) followed the same basic protocol during all of the interviews but freely explored

Table 1
Participant background information

Characteristic	<i>n</i> (%)
Sex	
Female	21 (70%)
Male	9 (30%)
Race	
White	24 (80%)
African-American	5 (17%)
Latino/a	1 (3%)
School level	
Middle school	18 (60%)
High school	12 (40%)
SES of school	
High ^a	14 (47%)
Low ^b	16 (53%)
Highest degree	
Bachelors—education	6 (20%)
Bachelors—science	8 (27%)
Masters—education	7 (23%)
Masters—science	8 (27%)
Ph.D.—science	1 (3%)
Years teaching	
1–5	18 (60%)
6–10	6 (20%)
>10	6 (20%)
Subject area	
Life science ^c	11 (37%)
Physical science ^d	4 (13%)
Earth-space science	3 (10%)
Integrated science	12 (40%)

^a<30% of the students classified as “economically disadvantaged” by the district.

^b>31% of the students classified as “economically disadvantaged” by the district.

^cIncludes Biology, Anatomy and Physiology, Ecology, and Environmental Science at the high school level or Life Science at the Middle School level.

^dIncludes Physics and Chemistry at the high school level and Physical Science at the middle school level.

ideas that teachers raised. The CAIs lasted between 30 and 90 minutes, with most lasting about 40 minutes. The interviewer recorded field notes during the interview in order to document the teachers’ actions to aid in the interpretation of the teachers’ comments.

Stage I of the Interview. The participants completed four different tasks during stage I. These tasks were designed to elicit the criteria that the teachers use to evaluate the acceptability or validity of an explanation. The first task, modified from one used in a study conducted by Sampson and Clark (2009), required the teachers to assess three alternative statements that can be used to explain why ice sitting on a block of aluminum melts faster than a piece of ice sitting on a block of plastic [see the Supporting Information for this task]. The second task called for the teachers to assess three different explanations that were provided to explain why water rises in an inverted flask when it is placed over a burning candle sitting in a shallow pan of water (Lawson, 2001). The third task required the teachers to assess three alternative explanations for observed variation in the coloration of Venezuelan Guppies. The fourth, and final, task prompted the teachers to assess three explanations for moon phases.

Table 2

The three stages of the cognitive appraisal interview (CAI) used in this study

Stage	Focus	Description of the Task	Duration (in minutes)
I	Determine how teachers evaluate alternative explanations for a natural phenomenon	Teachers are provided with a natural phenomenon, a focus question, three alternative explanations and a corpus of data about the phenomenon	10–20
	Identify the filters teachers use to assess the merits of an explanation	Teachers are then asked to determine which explanation is the most valid or acceptable and then articulate their reasons for their choice	
II	Determine how teachers craft scientific arguments	Teachers are asked to choose the most familiar topic and then create a written argument for the explanation they picked during stage I	15–25
	Identify what teachers think should be included in a scientific argument	Teachers are then asked to reflect on their own argument and arguments generated by scientists and explain what makes arguments persuasive in science	
III	Identify teachers' views about the integration of argumentation into the teaching and learning of science	Teachers are asked to explain their perceptions of argumentation for classroom use and describe impediments, describe views about the potential value of argumentation	5–10

At the beginning of each task, the teachers were introduced to the natural phenomenon to be explained. The teachers were asked to read the focus question, the three alternative explanations, and data that could be used to evaluate the explanations. The alternative explanations were crafted purposefully so that one would provide an answer that was sufficient and accurate from a scientific perspective, one would provide an accurate but insufficient answer (i.e., it did not fully explain why), and one that would provide a sufficient but inaccurate answer (i.e., it provided a full explanation but included one or more common misconceptions). Each task was presented one at a time and in the same order. Once a teacher had finished reading the task materials, they were asked to determine which of the three explanations was the most valid or acceptable. The teachers were also asked to explain their choice and to share what they were thinking as they evaluated the alternatives. Stage I of the CAI lasted between 10 and 20 minutes.

Stage II of the Interview. Once the teachers completed evaluating the alternative explanations, they were asked to choose the phenomenon that they felt they understood the best and then create an argument, in writing, to support their chosen explanation. This new task was designed to create a need for them to articulate the standards and criteria that they value in a scientific argument. We asked the teachers to write their argument for two reasons. First, we wanted to encourage the teachers to produce a complex and well-reasoned argument and the available literature suggests that people tend to produce written arguments that are more comprehensive than spoken ones (Erkens, Kanselaar, Prangmsma, & Jaspers, 2003; Reznitskaya et al., 2001). Second, we also wanted to give the teachers an opportunity to transform the corpus of data that we supplied to them into a data display if they thought that it was important to include a data display as part of their argument. The teachers were given unlimited time to craft their argument and none of the participants indicated that the task was challenging due to their writing skills. Once the participants were finished crafting their

written argument, they were asked to reflect on the process and to explain their views about what makes some scientific arguments more convincing or persuasive than others. Stage II usually lasted about 15–25 minutes.

Stage III of the Interview. In the final stage, each teacher was asked to explain his or her views about the potential value of engaging students in these types of tasks as a way to improve the teaching and learning of science. This final step of the interview usually lasted about 5–10 minutes. To conclude the interview, the teachers were asked to describe any types of professional development or resources that would help them promote and support student participation in scientific argumentation.

Data Analysis

The audio recordings from each CAI were transcribed verbatim. We then engaged in a typological analysis (Hatch, 2002) of the transcripts, written arguments, and the field notes. The first step in the typological analysis is to read through the entire data set and divide the various elements into topics based on predetermined categories. We organized our data set around three broad topics (or typologies) based on our specific research questions. The three topics, which were well aligned with the three stages of the CAI interview, included (1) strategies used by teachers to evaluate explanations, (2) characteristics of the arguments crafted by the teachers, and (3) teachers' views about the potential role of argumentation in science classrooms.

The next step in the analysis was to create a set of summary sheets for all 30 of the participants (Hatch, 2002). The summary sheets included an overview of what the participant said and did in relation to a particular topic, notes regarding the place in the original data set that the summary came from, and demographic information. The 90 summary sheets (3 topics \times 30 participants) produced allow us to condense the large amount of data into a descriptive account of the characteristics of each participant and the CAI.

The next step in the typological analysis was to use the summaries we created to look for potential patterns, relationships, and themes within each topic (Hatch, 2002). Patterns are regularities that appear across the participants. Given the nature of our research questions, we focused our attention on the identification of similarities in the ways the teachers completed the tasks and answered our questions. Relationships, in contrast, are links between the various elements in the data set and often temporal in nature. For example, we looked to see if certain types of responses followed or were frequently observed with another type of behavior or comment. Finally, we looked for themes within each topic. Themes are integrating concepts or statements of meaning the run through all the pertinent data (Hatch, 2002). Our goal during this stage of the analysis was only to identify potential patterns in the data we collected in light of our research questions and our topics that we used to organize the data set.

We then returned to the original data set and read through all the data within each typology to code it using the potential patterns, relationships, and themes identified previously. Once the entries were coded, we evaluated the utility of each identified pattern, relationship, or theme by assessing how well it was supported by the data and by searching for non-examples. We retained the interpretations that were well supported by all the available data and abandoned or modified the ones that were not. If we modified a pattern, relationship, or theme to better reflect the data we collected, we recoded the data within the particular typology using the modified interpretation and then began the evaluation process again. We continued this cyclic process of data analysis until all the patterns, relationships, and themes developed within each typology were a suitable interpretation of what the teachers said and

did during the interviews. This analysis resulted in a tentative answer for the first three research questions.

We expanded the focus of our analysis to answer the final research question. During this stage of data analysis, we needed to determine if the participants who engaged in similar practices or ways of thinking shared a similar background or teaching context. For this, we grouped all the teachers based on various demographic factors (e.g., education level, gender, and years teaching) and teaching context (e.g., subject area, school level, and SES of school) and then sought out similarities within each group. For example, we grouped the teachers by school level and then compared and contrasted the nature of the written arguments that were generated by the middle school teachers to the written arguments crafted by the high school teachers. We also grouped the teachers by a specific practice or viewpoint and then looked for similarities in the teachers' demographic background or teaching context to assess the merits of the commonalities identified earlier. We continued this process of grouping teachers and looking for similarities and differences until we felt that we had uncovered all possible commonalities.

Trustworthiness

We used a number of mechanisms to enhance the trustworthiness of our findings, including purposeful sampling, the triangulation of multiple data sources (e.g., interview transcripts, artifacts produced by the teachers, and field notes), an audit log, and member checking (Lincoln & Guba, 1985). We used purposeful sampling to ensure a diverse data set and included demographic information and details about the teaching context of the participants in this study to help readers judge the applicability of our findings. We triangulated findings through the use of interview transcripts, the artifacts produced by the teachers during the interviews, and the interviewer's field notes to both help identify different patterns or trends in the data and to help evaluate the merits of them. Member checking with six of the interviewees suggests that our analysis of transcripts was consistent with teacher thinking. Finally, we used an audit log to track our progress and decision-making.

Results and Discussion

We have divided the presentation of the results into four subsections and devoted one subsection to each research question. Each subsection includes a tentative answer to one of the research questions and a discussion of our findings. We also include excerpts from the interview transcripts and samples of the arguments produced by these teachers as support for our assertions.

How Do Practicing Science Teachers Evaluate the Validity or Acceptability of Alternative Explanations for a Natural Phenomenon?

This group of science teachers appeared to rely on a series of filters to evaluate the validity or acceptability of an explanation, and with few exceptions, each participant used these filters in the same order during each task. Figure 2 provides a diagram of the series of filters used by the participants in this study. In the paragraphs that follow, we will describe these filters.

The first filter was to determine if one of the three explanations fit with their existing understanding of the phenomenon. To do this, the teacher would first read over the introduction and the focus question, and then turn their attention to the three alternative explanations. The teachers would often make their choice at this point. To illustrate, consider the following excerpt. In this example, a female middle school teacher was asked to determine which of

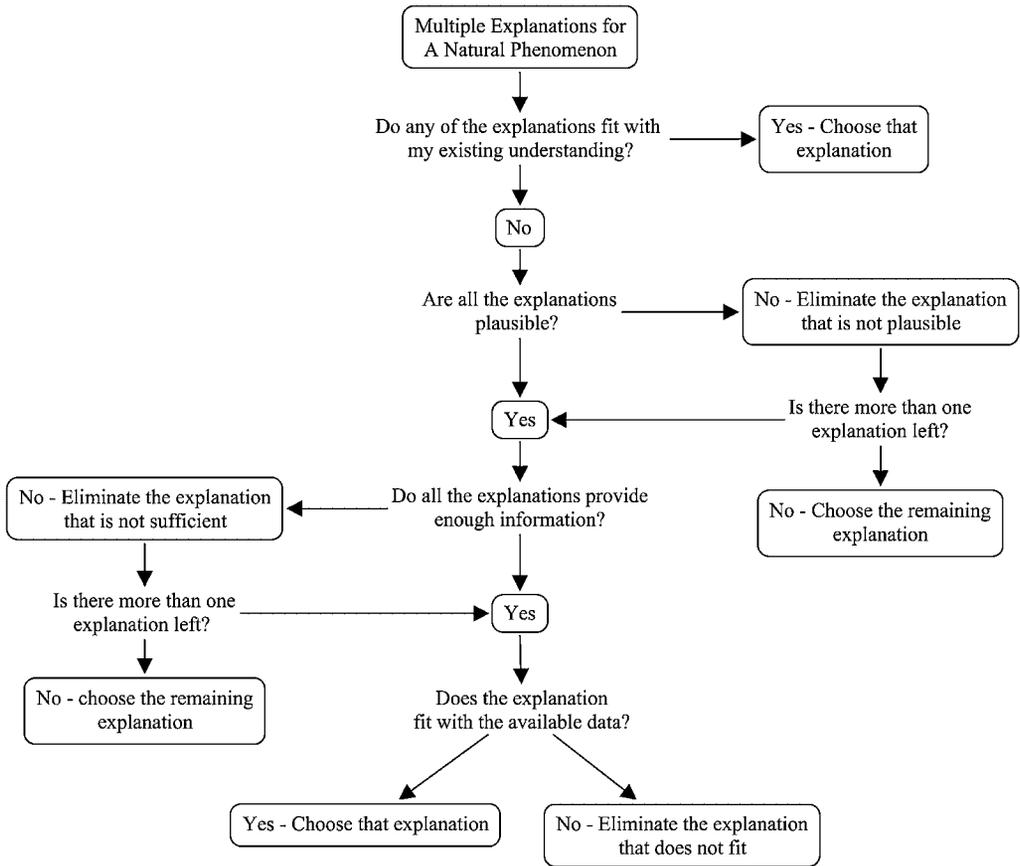


Figure 2. The filters used by the science teachers to evaluate alternative explanations.

three alternative explanations was the most valid or acceptable way to explain the phases of the moon. The teacher was provided with the materials at the beginning of the task (which included an introduction, the focus question, the three alternative explanations, and a calendar showing moon phases and moonrise/set times), then 12 seconds later, the following dialogue took place,

Teacher: It's the first one [The Moon looks different over time because the relative position of the Earth, Moon and Sun changes as the Moon orbits the Earth. As a result, we see varying portions of the sunlit side of the Moon].

Interviewer: Why do you say that?

Teacher: Because it's the correct explanation. I do lots and lots and lots of that with the kids—lots of different activities.

The second filter used by the teachers was to examine the nature of the explanations in light of the other explanations. This filter, however, was used only when one of the alternative explanations did not fit well with a teacher's existing understandings. The teachers often commented that they were trying to narrow the field of potential candidates. One female middle school teacher described this approach by saying, "I try to eliminate answers. When

I eliminate an answer it makes the final choice easier because I know which ones can't be it.”

To illustrate this strategy, consider the following excerpt. In this example, a male high school teacher was asked to determine which of three alternative explanations was the most valid or acceptable way to explain the observed patterns in the coloration of guppies. The teacher was provided with the materials and after 42 seconds, the following conversation took place:

Teacher: It's the second one [female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce. As a result, drab males are more common in pools with lots of predators and bright males are more common in pools with few or no predators].

Interviewer: Why do you say that?

Teacher: Well, this one was a little harder. I know the third explanation [the guppies were created to either be drab or bright so they would be able to survive in a specific habitat] can't be it because it says they're created and that touches upon creationism. The wording of the first one didn't make sense. I don't like the way it talks about natural selection. It doesn't go along with the idea that variations exist beforehand. My students use this type of wording quite a lot [to explain things]. So that left the second one.

Overall, the teachers would focus on one or two aspects of an explanation when they used this filter. The first aspect was the plausibility of the explanation. The second aspect was the sufficiency (i.e., the amount of information included in the explanation) or the overall clarity of the explanation (see Figure 2). A female high school teacher, for example, described the way she evaluated the alternative explanations presented during the second task by saying,

You have to read all of them to see which one sounds plausible. All of them have some plausibility to them. Then it was going back to them and looking at to ask, “How was this one worded, did it clearly explain the science well? Was it in a way that you could misconstrue the science?”

The last filter used by the teachers was fit with the provided data. This filter, however, was only used when a teacher could not distinguish between the alternative explanations using the other two filters. To illustrate, consider the following conversation that took place after a female high school teacher was presented with the *Venezuelan Guppy problem* (task #3):

Teacher: It's the second one [female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce. As a result, drab males are more common in pools with lots of predators and bright males are more common in pools with few or no predators].

Interviewer: Why do you say that?

Teacher: Well, I don't think that guppies can choose to become drab. The drab ones are in the pools where there are predators. If all of the brightly colored males are devoured the girls have to take what they can get. I really had to

look at the data to figure that out because I didn't know the answer. I didn't have to look at the data for the one about the candle.

This example not only illustrates how this teacher used the available data to distinguish between the alternative explanations but also how this teacher turned to the data only when she could not determine which explanation was the most valid using the filters described earlier. It is important to note that using criteria other than "fit with the available data" to evaluate alternative explanations is not unscientific in nature. In the argument framework we presented at the beginning of the article, we described a number of criteria that can be used to evaluate an explanation in addition to "fit with the evidence." Two of these criteria, "fit with accepted theories and laws" and "sufficiency of the claim," are aligned with certain aspects of the first two filters used by these teachers. For example, when a teacher explained why she picked one explanation over another by saying, "because it's the correct explanation" she was not being unscientific. She was simply basing her decision on her existing understanding of scientific theories, laws, or concepts just like scientists do. The teachers in this study used many but not all of the same criteria that scientists use to evaluate alternative explanations during the various tasks. This indicates that the strategies that teachers use to evaluate the validity or acceptability of an explanation are appropriate from a scientific perspective but tend to be limited in scope.

What Are the Characteristics of the Arguments Practicing Science Teachers Generate in Order to Support a Chosen Explanation?

All of the written arguments generated by this group of science teachers could be grouped into one of four different categories. These categories reflect different strategies that the teachers used to support a chosen explanation. In the paragraphs that follow, we will describe each strategy and provide example arguments to illustrate each one. We will then provide an overview of how the strategies compare to the argument framework previously presented.

The most common strategy was *to expand on the explanation*. To illustrate this strategy, consider the following argument that was produced by a high school teacher:

The chosen explanation: The Moon looks different over time because the relative position of the Earth, Moon and Sun changes as the Moon orbits the Earth. As a result, we see varying portions of the sunlit side of the Moon.

The teacher's argument: The phases of the moon are caused by how much of the moon is illuminated from the sun. Therefore as the moon revolves around the Earth the amount of illuminated area on the moon either gets larger or smaller depending on the position of the moon.

The argument produced by this teacher simply clarifies and adds to the chosen explanation by providing an unsubstantiated, and in this case inaccurate, inference.¹ The majority of the teachers in this sample produced this type of argument. What is interesting to note is that many of these teachers indicated that it was important to use data to support an explanation. For example, the author of the above argument noted, "you need to use collected data to back up your explanation." This suggests that there either is a disconnect between their ideas about what counts as a good argument in science and their argument skills or that many of these teachers have an inaccurate understanding of what counts as data in science.

The second most common strategy was to *use data and reasoning* as evidence to support a chosen explanation. To illustrate this strategy, consider the following argument that was produced by a female high school teacher.

The chosen explanation: Female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce. As a result, drab males are more common in pools with lots of predators and bright males are more common in pools with few or no predators.

The teacher's argument: The data provided shows that turbid pools with numerous predators have fewer brightly colored male guppies while clear pools with no or fewer predators have the "bright" boys. It seems likely that natural selection would favor the drab males that survive to become fathers over the "flashy" boys that attract the attention of a hungry cichlid and become dinner. The drab males that survive to be daddies pass this trait to their sons so that the population becomes predominantly "drab."

In this argument, unlike the first example, the teacher used some of the available data to support the validity of her chosen explanation. The teacher also explained why the information she provided in her argument supported the explanation. This is often described as a warrant (Toulmin, 1958) or reasoning (McNeill & Krajcik, 2008) in the science education literature. When this teacher was asked about what should be included in a scientific argument, she said, "Data should be listed as evidence. You also have to have reasoning, as a follow up to your evidence." The other teachers that produced this type of argument gave similar descriptions of what needs to be included a scientific argument. Overall, these arguments and perspectives on argument quality are a good match with many of the analytic frameworks that science education researchers use to examine the quality of students' arguments (Sampson & Clark, 2008).

The third most common strategy was to point out why the alternative explanations were unsatisfactory in their argument. To illustrate this strategy, consider an argument that was produced by a female middle school teacher:

The chosen explanation: Female guppies prefer to mate with brightly colored males. As a result, bright males tend to attract more mates and produce more offspring. When there are lots of predators in a habitat, however, brightly colored males do not survive long enough to reproduce. As a result, drab males are more common in pools with lots of predators and bright males are more common in pools with few or no predators.

The teacher's argument: Explanation one explains part of it, but explanation two goes more in depth. It says why the bright colored ones may not survive to pass on their genes in a pool full of predators (cause they'll stand out). It also explains why some guppies would still have bright colors in pools despite predators being present (sexual selection). Explanation one doesn't even attempt that. Explanation #3 doesn't provide a reason other than they have always been like that.

This type of approach is a rhetorical tool that is often used during informal or formal debates (van Eemeren, Grootendorst, & Henkemans, 2002; Walton, 1996). In this strategy, an individual attempts to dichotomize an issue so that if one position is discredited the audience is forced to accept the other. A male middle school teacher, for example, summarized this approach by stating,

Since there are all kinds of alternative theories, it's important if you believe one theory over another you have to find the holes in the theory that you are not supporting. You need to focus on why, not just what.

The least common strategy used by these teachers was to provide a *series of premises* in an attempt to guarantee the "truth" of an explanation. This strategy is similar in many ways to the arguments that *elaborate on or clarify an explanation* and the arguments that included *data and reasoning*. In this type of argument, however, the author's overall goal was to craft an argument that demonstrated how a particular explanation must be true in light of a sequential set of established facts or observations. To illustrate this strategy, consider the following example that was crafted by a female middle school teacher.

The chosen explanation: The candle uses up all the oxygen inside the flask. This creates a partial vacuum inside the flask. The water rushes up into the flask in order to fill this empty space

The teacher's argument: The third explanation is correct because:

- All atoms/molecules have a mass.
- Air consists of various molecules including O₂, CO₂, N₂, and other trace gases.
- Air was trapped inside the flask when it was placed over the candle.
- For a flame to exist oxygen must be present.
- A flame uses oxygen as it burns.
- As the flame was burning the water level rose.
- When the flame extinguished the water stopped rising.
- Because the oxygen was used up the air pressure inside decreased and the water was able to rise.

This argument, unlike the other three approaches, resembles the proofs developed by mathematicians. Mathematical proofs, however, are not intended to serve the same purpose as a scientific argument and are evaluated using different criteria. Mathematical proofs are used to demonstrate that a statement (or theorem) must be true in all cases. In contrast, scientific explanations can and do change in response to new evidence and often involve theoretical or unobservable processes that can only be inferred from empirical observation (Windschitl et al., 2008). As such, the overall goal of a scientific argument is not to prove that an explanation is true; rather the goal is to persuade others that a given explanation adequately accounts for a set of observations (Windschitl et al., 2008). This teacher, however, did not view a scientific argument in this manner as she explained her views about what counts as a good argument,

It is important to support your explanation with what you already know is true. You can use that information as part of your proof. The argument also needs to make sense. Nothing can contradict what you're trying to prove.

The other teacher in the sample that used this approach to craft her argument gave a similar description of what makes an argument persuasive. The way these teachers focused on proof and the ultimate truth is troubling because it indicates that they do not understand many of the fundamental principles underlying scientific inquiry and the nature of scientific arguments.

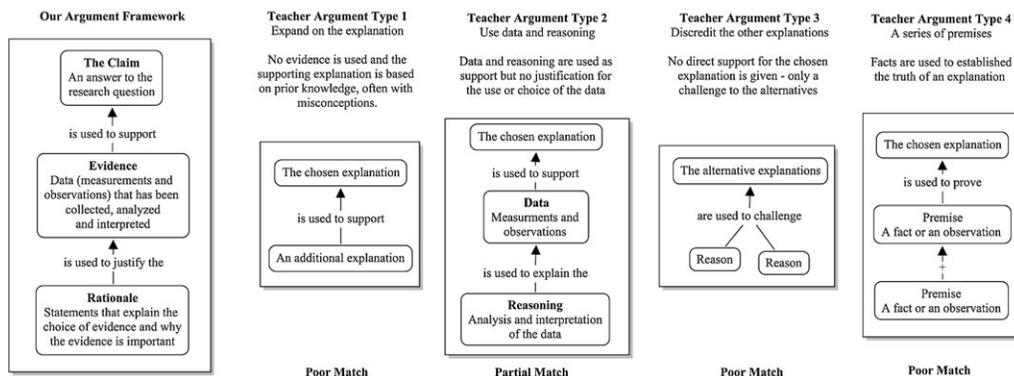


Figure 3. Types of arguments produced by the science teachers.

Figure 3 provides an illustration of the different strategies that the science teachers in this study used to craft their written arguments in relation to our model of an argument in science. Most of these teachers, as noted earlier, used another explanation that was based on their existing knowledge to support their chosen explanation rather than transforming the available corpus of data into evidence to support their written arguments. Even when the teachers did use the available data as support and made their reasoning explicit (i.e., included evidence), they did not provide a rationale that justified their choice of evidence. Therefore, most of these science teachers' arguments were not well aligned with the description of scientific arguments outlined in the national standards and reform documents (Duschl et al., 2007; National Research Council, 2008) or the analytical frameworks used by most researchers (Sampson & Clark, 2008).

Do Practicing Science Teachers Value Scientific Argumentation as a Way to Improve the Teaching and Learning of Science?

Reasons for Engaging Students in Argumentation. Each teacher was asked to share his or her views about the possibility of integrating argumentation into instruction. All the teachers in the sample indicated that it was an important and valuable way to improve student learning. The most common reason for this claim was that argumentation is a valuable way to get students to think. For example, one female high school teacher said,

We want our kids to be able to think when they read the paper. They are so used to seeing something and if it's written down it's true. We want our students to be able to say there's something wrong with that. Be able to evaluate and see there's more to it than what is just written down.

The second most common reason voiced by the teachers was its potential to help students develop an understanding of scientific inquiry, as described by this female high school teacher,

I think this would be really helpful. Students need to learn how to do science. We require them to write essays and lab reports where they explain, analyze, and use data they collect to draw conclusions but I think this would help them understand that they need to look at multiple explanations and it would help them understand why evidence is so important in science.

Only a few of these teachers indicated that engaging students in argumentation could help students develop an understanding of the content, as explained by a female high school teacher,

I think argumentation is really good for getting the ideas out for students especially at high school where they have had more experience and are more intellectual, where they can comprehend more—they've learned these things [points to the task about the phases of the moon] before in elementary school—a lot of times. They still can't explain why these things have happened.

Overall, our analysis of these data indicate that many of these teachers think that argumentation, as an instructional activity, can help students reason or understand the nature of scientific inquiry better but only a few see it as a way to improve student understanding of the theories, laws, or concepts of science. Current research, however, indicates that students also can develop a better understanding of the content when they have a chance to discuss and evaluate 'how they know' in addition to 'what they know' (Duschl et al., 2007; National Research Council, 1999).

Potential Barriers to Using Argumentation Inside the Classroom. These teachers also voiced concerns about efforts to integrate argumentation into the teaching and learning of science. These concerns usually focused on potential barriers to student engagement in argumentation inside the classroom. It seemed that these issues made the teachers feel uneasy about using activities designed to give students an opportunity to participate in argumentation inside their own classrooms and some skepticism about the potential benefits of such activities.

The most common barrier discussed by these teachers was the achievement or "ability" level of their students. For example, one male high school teacher said, "The high achieving students really would like it. The others won't really care." Another female high school science teacher commented, "They don't write very well. They have a lot of trouble with this—backing up their information. They have a hard time with language." These types of comments suggest that many of these teachers believe that most students in their classroom lack the skills, knowledge, or habits of mind needed to engage in scientific argumentation.

These teachers also seemed to think that students must know how to engage in scientific argumentation before they can be given a chance to evaluate evidence, assess alternatives, or establish the validity of a scientific claim during a lesson. For example, one female high school teacher said, "My students are really not ready for this yet." Similarly, a female middle school teacher commented, "I would only let students that can handle it [argumentation] do it." These types of comments indicate that many of these teachers view scientific argumentation as something that is too difficult for most students to handle and, as result, should be avoided. In fact, only a few of the teachers who mentioned this potential barrier indicated that students would need time to learn how to engage in argumentation over the course of a school year. For example, a female high school teacher said,

I think they [the students] would really struggle with this [argumentation] at first. They would really need lots of practice in order to get better at it. But hey, you learn best by doing, right?

The other teachers seemed to share a perception that most students would be unable to do it, that it would be counterproductive to learning, or that students would struggle too much

with the process so it would be better not to attempt to engage students in argumentation during a lesson at all. For example, a male high school teacher said,

It may be too hard for them because if they don't have enough background knowledge they might think any explanation would make sense. I know with the moon one a lot of kids do think it is the shadow, they may see the explanations and say well it's written right here this is what I think and those students would pick that. I wouldn't want that to happen. You can run the risk of reinforcing misconceptions.

And a male middle school teacher commented,

The students at this level are so trained to listen and not be heard. You see that with the family life. They never question things. They are told what the answers will be. I am not sure they could handle something like this.

Another concern that was voiced by a majority of the teachers was the issue of time. One female high school teacher explained, "You don't have the time to do that in high school you have so many topics to cover in a class." Many teachers understood that argumentation could be added to the curriculum when there is time, as explained by this male middle school teacher,

I don't know if you could do an entire curriculum based on this style because you have to do the nuts and bolts of content and make sure they develop a good foundation. I think at this level I would enjoy doing this with a class on Fridays.

The final potential barrier discussed by a majority of the teachers in this sample was their lack of knowledge of how to engage students in argumentation and the limited resources available to assist them. This concern, however, was not unexpected given the existing literature (e.g., Simon et al., 2006). As a result, the teachers often commented that they would need materials and support to integrate argumentation into the teaching and learning of science. A male high school teacher, for example, said,

I think if I had a library of ideas to pull from... a workshop where teachers by subject matter could have a chance to work together to develop this or come up with ideas together. Have a web server where you can put a library together of teachers' ideas. I think teachers would be more apt to implement this when they don't feel they have to make it from scratch.

The types of comments offered indicate that many of these teachers view activities that require students to evaluate alternative explanations or develop arguments as too difficult for most students. Most of these teachers viewed argumentation as an instructional strategy that should only be used with "high ability" students because it would be too difficult for the low achievers. Many of the teachers also indicated that argumentation would be too time consuming or that lessons designed to promote and support student participation in argumentation would be a good supplemental activity that could be used after "covering" the course content. These potential barriers or obstacles, however, are not supported by the available literature. In fact, current research indicates that all students, regardless of current achievement level, are able to engage in complex practices such as argumentation inside the classroom (McNeill et al., 2006; Rosebery, Warren, & Conant, 1992) and that engaging students in argumentation can help students to develop a better understanding of the theories, laws, and models of science (Bell & Linn, 2002).

Do Practicing Teachers Evaluate Explanations, Craft Arguments, and View Argumentation Differently Based on Background and Teaching Context?

In order to answer this question, we looked to see if the teachers with similar backgrounds and teaching contexts engaged in the two aspects of argumentation and viewed the possible integration of argumentation into the teaching and learning of science in a similar manner. We identified several interesting trends related to the characteristics of teachers who used data to evaluate explanations, the types of arguments the teachers with different backgrounds produced, and how context appears to be related to a teacher's views about argumentation. We will present these trends in a sequential order around these issues; however this does not mean that some of these trends are more meaningful than the others. It is also important to note that these trends are limited to the teachers in this sample and should not be interpreted as conclusions that can be generalized to all science teachers.

The Characteristics of the Teachers Who Used Data to Evaluate Explanations. Sixteen of the teachers in this sample did not use the corpus of data provided and another eight of them only used this information during one of the tasks. This means that only 6 of the 30 teachers who participated in this study used the data provided as a way to evaluate the validity of the alternative explanations on more than one of the tasks. This, however, does not mean that these teachers were unscientific in the way they approach these tasks. There are numerous criteria that can be used to evaluate alternative explanations in science. Along with empirical criteria such as 'fit with available data,' scientists also use theoretical criteria such as 'predictive power' or 'sufficiency of the explanation' and analytical criteria such as 'appropriateness of the interpretation' to determine if a proposed explanation is valid (Chinn & Malhotra, 2002; Driver et al., 2000; Sandoval, 2005). There were some similarities in the educational backgrounds of the teachers who used the data to evaluate explanations more than those who did not.

Four of the six teachers who used the available data to evaluate the alternative explanations on two or more task did not have an undergraduate degree in a science and five of these teachers had been teaching for less than 6 years at the time of the interviews. In contrast, 11 of the 16 teachers who never used the available corpus of data during any of the tasks either had an undergraduate or graduate degree in a science and nine of these teachers had been teaching for 6 or more years at the time of the interviews. This trend suggests that the teachers who had more coursework in a natural science and had been teaching science longer (which is presumably associated with more content knowledge) often did not use the available corpus of data to evaluate the alternative explanations. This trend is well aligned with the series of filters that we described earlier. The first and most common filter used by these teachers to evaluate an explanation, regardless of the scenario, was to see how well it matched with their personal understanding of the phenomenon. In this light, these results are not surprising as these teachers simply relied on their content knowledge to complete all four tasks. For example, a male high school teacher with a master's degree in a natural science described how he used his content knowledge to evaluate the various sets of alternative explanations when he said,

I would say a lot of my choices were based on personal experience or background knowledge. If you've studied this content you just know it. I learned some of it in the classes I took and some of it from the books I have read.

The teachers without strong content knowledge, in contrast, needed to use the available data to determine which explanation was the most valid or acceptable because none of the

explanations matched with their understanding of the phenomenon. The teachers with weaker content backgrounds or years teaching usually relied on the other sets of filters to complete the tasks.

The Characteristics of the Teachers Who Crafted a Certain Type of Argument. The teachers in this sample, as noted earlier, crafted one of four different types of arguments during the second stage of the interview. The most common strategy was to support a chosen explanation by providing another explanation that expands or clarifies it. This strategy was used by 14 of the teachers. The next most common strategy, used by 10 teachers, was to use data and reasoning as evidence to support an explanation. The two least common strategies used were to create an argument that refutes the alternative explanations, which was used by four of the teachers, and to establish the truth of an explanation with a series of premises, which was used by only two of the teachers in the sample. The only strategy used by these teachers that was aligned with the argument framework we introduced at the beginning of this article, however, was to use data and reasoning to support the explanation. The infrequent use of data and reasoning in the teachers' arguments is cause for concern because it indicates that many of these teachers have an inadequate understanding of the nature of scientific arguments.

There were some similarities, however, in the educational backgrounds of the teachers who used data and reasoning in their arguments and for those who did not. Eight of the 10 teachers who used data and reasoning to support the explanation they selected had a graduate degree in science or education, while 8 of the 14 teachers who simply expanded or clarified the explanation of the choice had an undergraduate degree. One potential explanation for this observation might stem from the differences in the nature of instruction at the undergraduate and graduate level and the lack of an explicit focus on argument in science courses. Almost all of the teachers we interviewed claimed that they never learned how to craft a scientific argument while they were in school. The following comment, which was made by a teacher who had an undergraduate degree in a science and a master's degree in education, is typical of how many of these teachers described their own science education,

I have no memory of science in middle school. In high school I was bored to tears. Chemistry was just a big confusing hour. I remember balancing equations. In environmental science we watched videos and took notes. In biology—a lot of reading text. . . . In college it was pretty much the same—a lot of note taking and lectures. I didn't have to write and provide support for what I was saying until graduate school.

It should not be surprising that these teachers were unfamiliar with the nature of arguments in science. Most of them never learned about scientific arguments as part of their coursework and they were not expected to support their explanations with evidence and a rationale by their instructors—at least at the undergraduate level. These teachers, as a result, tended to focus on explaining what happened instead of focusing on how they know what they know and why others should find an explanation valid or acceptable. These teachers' experiences with science as students coupled with their emphasis on explaining the "right" answer when teaching might help explain why only a minority of the teachers in this sample crafted an argument that included data and reasoning. This potential explanation might also account for the disconnect we observed between the characteristics of some of the arguments teachers crafted and their views about what needs to be included in scientific arguments. As we described earlier, some of these teachers said that scientific arguments need to include data as support but crafted an argument including explanations. These teachers might think

that an explanation counts as evidence in science because they have never been taught otherwise.

The Characteristics of the Teachers Who Shared Certain Views About Using Argumentation as Part of the Teaching and Learning of Science. Most of the participants in this study indicated that the integration of argumentation into the teaching and learning of science would encourage students to think more (24 teachers) and/or would help students develop a better understanding of scientific inquiry (17 teachers). Only two of the teachers in the sample, however, viewed argumentation as a good way to help students understand the content better. Teachers also mentioned several potential barriers to integration of argumentation. The most common barrier, which was voiced by 28 teachers, was their own lack of knowledge of how to structure argumentation activities or how to assist students. Eighteen of the teachers mentioned the “ability” level of students as a major obstacle or that it was too hard for all their students. Not surprising, a majority of the teachers described that argumentation would take time away from their ability to cover all the state science standards.

There were several trends that we were able to identify when we examined teachers’ views by teaching context. First, a greater proportion of the teachers who work in low SES schools (14 out of 16) mentioned the ability level of their students as a potential barrier to their use of argumentation into the classroom when compared to the teachers who work at a high SES schools (4 of 14). Teachers at the low SES schools also noted that evaluating alternatives and crafting arguments in support of claims would be too difficult for their students (11 of the 16 teachers) more frequently than the teachers from the high SES school (7 of the 14 teachers), although many of the teachers from the high SES schools also thought that their students would not be able to “handle” participating in argumentation at all during a lesson or a unit. The teachers at the high SES schools, in contrast, seemed to be more concerned with time constraints (10 out 14 teachers) than the teachers at the low SES schools (6 out of 16 teachers). A similar trend was also observed when we compared the views of the high school and middle school teachers. Middle school teachers were much more concerned with the ability levels of their students (12 out of 18 teachers) and how difficult argumentation would be for them (13 out of 18 teachers) than the high school teachers. Six out the 12 high school teachers voiced their concern about the students’ abilities and five mentioned that argumentation might be too difficult for their students. The high school teachers seemed to be much more worried about time (10 out 11 teachers) than the middle school teachers (mentioned by only 6 of the 18 teachers). These trends illustrate how context can influence a teacher’s views about the integration of argumentation into the teaching and learning of science.

Conclusions

The science teachers in the study often relied on their content knowledge and past experiences to evaluate the validity or acceptability of an explanation for a natural phenomenon rather than available data. These teachers, as a result, only used the available data as a way to differentiate between alternatives when they were unsure of their own ideas. The following quote, which was provided by a female middle school teacher, clearly reflects this type of mindset.

First, I take into account what I’ve studied. Does this explanation fit with what I know? Then I try to eliminate one example immediately based on how much information it gives or if it’s not as detailed as the other. I learned how to do that in school from multiple-choice tests.

Scientific explanations can and should be evaluated using a wide range of criteria including, but not limited to ‘adequacy of the explanation,’ ‘fit with other accepted theories,’ and ‘fit with the available data.’ Therefore, evaluating an explanation using criteria such as, ‘fit with personal theories’ or ‘the amount of detail included in comparison to other explanations’ does not align well with the scientific habits of mind outlined in reform documents (Duschl et al., 2007; National Research Council, 2008). It also does not reflect the nature of argumentation in science, which is characterized by certain epistemological commitments or criteria that are used to evaluate or assess the validity of an explanation (Duschl & Osborne, 2002; Sampson & Clark, 2009, 2011). Encouraging students to use everyday strategies such as ‘eliminate the ones that don’t fit with what you know’ or ‘eliminate the options that are not as detailed,’ therefore, might not be the best way to teach students how to assess the validity or acceptability of alternative explanations in science (Sandoval, 2005). Indeed, this type of strategy might be detrimental to a student if the student (or the teacher) bases his or her evaluation on a common alternative conception or if the explanation underlying a natural phenomenon is counter-intuitive. In fact, many of the teachers in this study chose an explanation that provided a detailed but inaccurate explanation on at least one of the tasks because they relied only on their own personal understanding of the phenomenon.

Many of the teachers we interviewed created written arguments that did not provide any genuine support for an explanation. Instead, most of these teachers either elaborated on an explanation or simply attempted to discredit one of the alternatives. Only a few of the teachers in this sample created an argument that included evidence as support and none of these teachers included a justification of the evidence that they decided to use. Given the focus on “final form science” instruction in the United States (Duschl, 1990), it should not be surprising that these teachers focused their attention on providing a clear explanation for a natural phenomenon rather than using evidence to support it. In science, however, it is not enough to point out weaknesses in an explanation or explain why an alternative lacks support; explanations need to be supported by evidence in order to be convincing or persuasive. This is one of the many ways scientific arguments are different than the arguments that are used in other contexts.

Yet, it is important to note that these teachers are a product of the education system that currently is in place and argumentation has traditionally not been emphasized in science classrooms (Berland & McNeill, 2010; Duschl & Osborne, 2002). For example, after being asked if he ever needed to evaluate explanations or craft scientific arguments as part of his education, a male middle school teacher with an undergraduate degree in a natural science said the following:

I don’t recall ever having a class like that. I had to answer open-ended questions where you write out your answer a lot but I was only graded based on the accuracy of my answer, not how well I could support it.

It is unreasonable to expect science teachers to be able to participate in scientific argumentation or understand how the nature of scientific argumentation and arguments differ from what often takes place in other contexts if they have never had a chance to learn about this complex practice.

Most of the teachers we interviewed doubted that their students could participate in argumentation and were concerned that it would require too much time to implement, which are reservations consistent with those expressed by other science teachers in the literature (Lumpe, Haney, & Czerniak, 2000). A vast majority of the teachers also felt they lacked the

knowledge or resources to use argumentation effectively. This lack of pedagogical knowledge is an interesting juxtaposition to the fact that teachers rely heavily on their content knowledge to evaluate the validity or acceptability of alternative explanations rather than available data. In addition, many teachers' understanding of what counts as a high quality argument in science does not seem to reflect current curriculum development efforts (e.g., McNeill et al., 2003; Passmore & Stewart, 2002) or the analytical frameworks used in science education research (Sampson & Clark, 2008). Science teachers, however, do seem to value argumentation as a way to improve the teaching and learning of science, although they have a number of reservations about it. These teachers, as a result, are unlikely to incorporate argumentation into their teaching without a great deal of support, resonating with findings from other professional development settings (Blanchard, Southerland, & Granger, 2009; Crawford, 2007).

The actions and views of this group of teachers seemed to be shaped by their educational background and their teaching context. The teachers with an undergraduate or graduate degree in a scientific field would often rely on their content knowledge rather on the available data to evaluate the explanations. The teachers with a graduate degree seemed to be more inclined to craft arguments that included data and reasoning than the teachers with an undergraduate degree, regardless of content area. This trend suggests that education level may play a role in the ways teachers engage in argumentation. Teachers who work in middle schools or schools that serve students that are poor were more inclined to view argumentation as something that their students are unable to do, either because of their natural abilities or lack of preparation. This trend suggests that teaching context may influence the way a teacher views the role of argumentation.

We caution the reader, however, that our conclusions need to be viewed in light of several caveats. First, this study was qualitative in nature so our findings should not be generalized beyond this sample. We did, however, provide information about the participants and the instructional context to allow readers to determine how applicable our findings are to other contexts. Second, we need to acknowledge that we have based many of our claims on what the teachers told us about how they think. Therefore, like all studies that use self-report data, there is a chance of biased responses. Finally, although our sampling technique involved a wide range of teachers from school district, it is possible that this sample was not representative of the views and knowledge of the population of teachers who work in the district.

Implications

Teachers can use research-based curriculum materials and instructional strategies to promote and support more student engagement in scientific argumentation inside the classroom. However, as the available literature suggests, we cannot assume that the use of these resources will look the same in all classrooms (Blanchard et al., 2010). Teachers will often adapt, refine, or even disregard entire aspects of a curriculum or an instructional strategy based on the own understanding of the resource, their knowledge of the content, their unique classroom context, and the value they place in them (Keys & Bryan, 2001; McNeill & Krajcik, 2008). It will therefore be important for science educators who are interested in integrating argumentation into the classroom to focus more on how teachers use these resources and what science teachers know about argumentation. Given this, this study has several important implications for science teacher education.

First, science teacher educators will need to help pre-service and in-service science teachers learn more about the nature of scientific argumentation, if other science teachers share the strategies for evaluating explanations and crafting arguments described in this article. For example, the science teachers in this study clearly needed to learn more about the structure of

a scientific argument and how to assess alternative explanations based on evidence. Other teachers, therefore, might share this need as well. One way to help teachers learn more about the nature of scientific argumentation and arguments is to engage them in activities such as the tasks used in this study. Science teacher educators can then use these experiences as a foundation to help make the aspects of a scientific argument explicit. Then, teachers can be introduced to the various instructional resources that have been developed to promote scientific argumentation. Over time, this should help science teachers develop the knowledge and skills they will need to integrate more argumentation into their classroom.

The second implication that can be drawn from our findings is the importance of addressing teachers' concerns about the use of argumentation in the classroom in pre-service or in-service science teacher education programs. Many of the teachers we interviewed voiced concerns about the "ability" of their students, the amount of time needed to engage students in argumentation, and a lack of resources. These concerns are similar to the ones voiced by teachers in other contexts and can act as a major barrier to classroom reform (Lumpe et al., 2000). Therefore, it will be important for science teacher educators to address these barriers with professional development that is centered on the needs of the teachers. Focusing on these issues while helping teachers develop a better understanding of scientific argumentation should increase the likelihood that science teachers will attempt to teach science as "explanation and argument."

A third implication relates to the goals and views of science teachers. Regardless of the goals for student learning that are outlined in the national science education reform documents (Duschl et al., 2007; NRC, 2008), helping students master the content in each grade level is the primary goal of most science teachers (Driver et al., 2000). Most of the teachers who participated in this study, however, did not view argumentation as a way to help students learn content even though current research suggests otherwise (Bell & Linn, 2000; Zohar & Nemet, 2002). If other teachers share this view, it is unlikely that these teachers will embrace any new curriculum, instructional strategy, or technology-enhanced learning that is designed to engage students in argumentation. This highlights the importance of science educators to persuade teachers that students can learn *from* (i.e., content) and *about* (i.e., the process) argumentation at the same time as part of the professional development associated with the new materials or approach.

Finally, scientific argumentation is an aspect of science that was clearly unfamiliar to most of the science teachers in this study. Yet, these teachers, like so many others in the United States, will be expected to give their students an opportunity to learn how to participate in scientific argumentation (Duschl et al., 2007; National Research Council, 2008). Many of these teachers, as a result, will need to learn a new set of skills. Many of the teachers might also have views about teaching, learning, and their students that are at odds with these new expectations. Our findings about how this group of teachers engaged in two important aspects of scientific argumentation and their views of argumentation as an instructional strategy are therefore a valuable resource for science teacher educators. This information not only provides insight into what to look for in other contexts but it also provides a foundation for meaningful professional development for in-service teachers and program revisions for pre-service teachers.

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Note

¹This inference is inaccurate because the amount of the moon that is illuminated by the sun does not change (except during an lunar eclipse). It is the amount of the sunlit side of the moon that we are able to see from Earth that changes over time.

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