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Argumentation: The Language of Science

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Introduction

In the past two decades, the role of language in the science curriculum has become prominent in science education literature (e.g., Dawes, 2004; Gee, 1989; Lemke, 1990; Yore, Bisanz, & Hand, 2003). From a constructivist perspective, language mediates social interaction and meaning is constructed as learners interpret and reinterpret events through the lens of prior knowledge (Barnes, 1992; Berk & Winsler, 1995). This perspective applied to the science classroom results in the view that scientific knowledge is socially constructed, negotiated, validated, and communicated in the context of the specific discourse practices of science (Driver, Asoko, Leach, Mortimer, & Scott, 1994). The rhetorical goal of scientific discourse is consensus based on evidence rather than compromise or conciliation achieved through democratic processes. As scientists attempt to reach consensus, they engage in a process known as *argumentation* whereby they attempt to persuade others of the validity of their claims. In fact, argumentation has been called the *language of science* (Duschl, Ellenbogan, & Erduran, 1999). Argumentation has also been identified as a possible mechanism for conceptual growth and change (e.g., Driver et al., 1994; Mercer, Dawes, Wegerif, & Sams, 2004; Nussbaum & Sinatra, 2003).

In this article, I begin by briefly discussing forms of argument and describing two frameworks that may be used to analyze arguments. Next, I review the science argumentation literature, highlight themes, and examine research trends. Finally, I pose questions that could be addressed by future research and reflect upon two pedagogical implications that arise in the science argumentation literature.

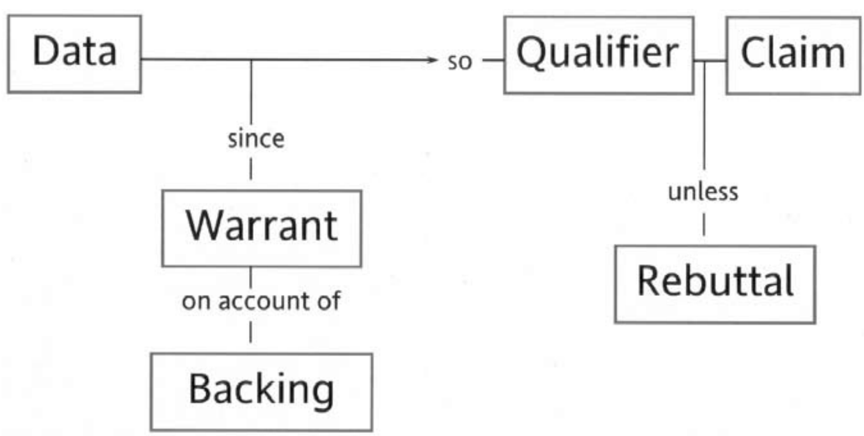
Forms of Argument

Arguments can be classified as rhetorical, dialectical, or analytical (Duschl & Osborne, 2002). *Rhetorical* or *didactic arguments* are used to persuade others by presenting one point of view as more convincing than the alternatives. They are one-sided arguments and are frequently discursive in nature (Driver, Newton, & Osborne, 2000; Yore, 2003). *Dialectical arguments*, sometimes referred to as *dialogical* or *multivoiced arguments*, involve the examination of differing perspectives during discussion or debate. *Analytical arguments* follow the rules of logic (e.g., Toulmin, 1958) and may be inductive or deductive (Duschl & Osborne, 2002; Yore, 2003). Inductive arguments include analogies and causal correlations, while deductive arguments include syllogisms and causal generalizations (Duschl & Osborne, 2002). Current science education reform emphasizes the use of dialectical and analytical arguments while deemphasizing rhetorical arguments, which traditionally have been predominant in the classroom (Driver et al., 2000).

Frameworks for Argument Analysis

Just as there are a variety of forms of argument, there are a variety of frameworks that can be used to analyze arguments. Much of the argument analysis in science education research has been based on the pattern of argument described by Toulmin (1958) (e.g., Bell & Linn, 2000; Mason & Santi, 1994). Toulmin's Argument Pattern (TAP) contains six elements as shown in Figure 1: (1) data, (2) warrants, (3) backings, (4) qualifiers, (5) rebuttals, and (6) claims (Erduran, Simon, & Osborne, 2004). *Data*, the facts that are appealed to in support of a claim, are considered evidence if there is a classificatory, comparative, or statistical relationship between the data and the claim (Yore, 2003); *Warrants* are the rules or principles used to justify the relationship between the data and the claim; *Backings* are the underlying assumptions that provide the justification for a warrant; *Qualifiers* are statements of the conditions under which the claim will be true, and they place limitations on the claim; *Rebuttals* are statements of the conditions under which the claim will not be true; and *Claims* are the conclusions whose merits are to be established through argument.

Figure 1. Toulmin's Argument Pattern



Source: Toulmin (1958)

The application of TAP, which emphasizes the generic features of argument, is described in detail by Erduran et al. (2004). TAP has also been used to evaluate the quality of argument, although the appropriateness of this type of application has been questioned because of the unproven assumption that the inclusion of particular elements of argument indicates quality (Mason & Santi, 1994; Osborne, Simon, & Erduran, 2004; Yore & Treagust, 2006).

Other science education researchers have used an alternate framework for analyzing science argument. Walton (as cited in Duschl & Osborne, 2002) proposed an argumentation scheme for presumptive reasoning that contains 25 categories of argument and emphasizes the content of argument, focusing on evidence and premises. Researchers using Walton's presumptive reasoning scheme have tended to use only selected portions of the scheme (e.g., Jiménez-Aleixandre & Pereiro-

Muñoz, 2002) or they combine categories to obtain a more workable analytical framework (e.g., Duschl et al., 1999).

Literature Review

The science argumentation literature is quite limited, consisting of more expert opinions than research, although researchers have examined general discussion in science contexts (e.g., roles in small group science discourse) and argumentation in other contexts (e.g., in social studies classes). For example, Felton (2004) worked with 7th- and 8th-grade students (ages 12 to 14) in a social studies context. Students who argued about capital punishment were able to improve their arguments in a reflection activity in which students with the same view compared warrants and rebuttals before arguing with a student who held the opposing view. It is important to note, however, that the results of such studies may not be generalizable to science argumentation because what counts as a good argument depends on the context—a point made by Newton, Driver, and Osborne (1999) when they proposed that argumentation was a crucial component of science education if students were to learn about the nature of science while they learned science content. Therefore, this literature review is limited to those studies and expert opinion pieces that have focused on argumentation in the science classroom. In addition, the literature review is limited to oral argumentation, although arguments can be spoken or written. The literature review begins with a brief description of the origins of science argumentation research, continues with a list of common themes and a discussion of the trends that are emerging in research results, and ends with questions for future research and implications for teachers.

Development of Science Argumentation Research

Although language education researchers in the 1960s and 1970s discovered that children use speech for a variety of functions (e.g., Halliday, 1969; Tough, 1977), it was not until the 1990s that science education researchers began to focus on a distinctly different pattern of discussion that sometimes could be observed (e.g., Doig, 1997; Lemke, 1990; Vellom & Anderson, 1999; Warren & Rosebery, 1995). Instead of focusing on procedural issues, students would seek evidence and reach collaborative decisions, as shown in Table 1. In 1993, Kuhn proposed argument as a metaphor for science as she attempted to connect children's informal thinking in science with scientists' formal thinking. Around the same time, Driver et al. (1994) pointed out that learning science should include learning scientific ways of knowing, and they identified argumentation as the epistemological basis of science. At that point, argumentation became a focus for some science education researchers, and the argumentation literature accumulated.

Table 1. Patterns of Science Discussion: 5th-Grade Students (Ages 9 to 10)

Procedural Focus (Dawes, 2004, p. 691)	Argumentation Focus (Mercer et al., 2004, p. 369)
Hannah: I choose which materials we go on—measure. Results 0.7. Right write – write 'glass.' [Points to screen.] *Darryl:* Write 'glass' [Points to screen. Deborah writes.] *Hannah:* 0.7. Cork 0.6 C.O.R.K. 0.6. Right, let's try– *Deborah:* It's someone else's turn. *Darryl:* It's my turn [Darryl takes the mouse.] *Hannah:* We've done glass haven't we? *Deborah & Darryl:* Yes *Darryl:* It's my turn. We done that.	*Alana:* Dijek, how much did you think it would be for tissue paper? *Dijek:* At least ten because tissue paper is thin. Tissue paper can wear out and you can see through, other people in the way, and light can shine in it. *Alana:* OK. Thanks. *Alana (to Ross):* Why do you think it? *Ross:* Because I tested it before! *Alana:* No, Ross, what did you think? How much did you think? Tissue paper. How much tissue paper did you think it would be to block out the light? *Ross:* At first I though it would be five, but second– *Alana:* Why did you think that?

As I read through the argumentation literature—both expert opinion pieces and primary research—I identified some common themes such as the importance of authentic learning and the related idea of a community of learners/validators, the need for explicit instruction in argumentation and for multiple opportunities to practice argumentation skills, the existence of multiple discourses, and the increasing emphasis on the role of metacognition in argumentation. Many of these themes are theory-based rather than research-based, and the limited research on science argumentation does not yet permit a detailed exploration of these ideas. However, in the following section, I present the trends that are beginning to emerge from the studies that have focused specifically on science argumentation.

Research Results

Although argumentation research is a growing area of interest, the number of published studies that focus on argumentation in the context of science is still relatively small. Despite the lack of a comprehensive body of research results, my review of the literature revealed five emerging trends. In this section, I present each of the five trends in the form of a claim and then provide evidence from two or more studies to support that claim:

1. **Explicit instruction helps students argue more effectively.** Bell and Linn (2000) worked with middle school students (approximate ages 11 to 14) who were studying light and who used *SenseMaker*, a computer program designed to scaffold argument construction and to make thinking visible. Their findings indicated that the process of building arguments might promote knowledge integration. They also found that student belief about the nature of science as dynamic was related to the development of more complex arguments. Mercer et al. (2004), in a project involving teachers and 5th-grade students (ages 9 to 10) during a unit on light and sound (see Table 1), examined the effects of teacher scaffolding of student

argumentation. Teachers were shown how to scaffold students' attempts at critical questioning, sharing information, and negotiating decisions. Results indicated that students in the experimental (argumentation efforts scaffolded) group made more detailed contributions to discussions and worked more collaboratively to reach consensus than students in the control group.

2. **Professional development helps teachers emphasize argumentation and scaffold it more effectively.** Newton et al. (1999) surveyed 14 experienced science teachers and found that many of the teachers commented on the need for more professional development to build the skills and confidence that are necessary for managing discussions and facilitating argumentation. The possibility that professional development could lead to more effective teacher implementation of argumentation was investigated by Simon, Erduran, and Osborne (2006), who conducted a two-year study of 8th-grade science teachers. They found that ongoing professional development enabled teachers to adapt and develop their classroom practice to include the use of argumentation. In addition, both the quality and quantity of student argumentation, as measured by the TAP rubric, increased as teachers incorporated argument-based lessons (Osborne et al., 2004).

3. **Well-established ground rules for acceptable argumentation enable more students to participate in focused argumentation.** Vellom and Anderson (1999) worked with 6th-grade students (ages 11 to 12) who were studying the density of liquids, and they allowed students to determine the norms, or ground rules and acceptable behaviors, for discussion as the community of validators developed. They noted that the argumentation process did not seem as effective for marginalized students. In contrast, Mercer et al. (2004), who worked with 5th-grade students (ages 9 to 10) studying light and sound, established argumentation norms through explicit instruction. They found that resulting discussions were more likely to be on-task and that students in the experimental (argumentation norms established) group were more likely to demonstrate argumentation skills than students in the control group. Mercer et al. claimed that establishing ground rules created an equitable intellectual environment and neutralized issues of social status, leading to greater participation for marginalized students.

4. **Explicit instruction and established ground rules for argumentation promote increased conceptual growth and change.** Mercer et al. (2004), in their study of 5th-grade students (ages 9 to 10) who were learning about light and sound, found that students in the experimental (argumentation) group had significantly higher scores on a concept map assessment than students in the control group. Nussbaum and Sinatra (2003), who focused on undergraduates and Newtonian physics, found that although a similar percentage of students in both the experimental and the control group were able to answer computer-simulated problems correctly, the students in the experimental group showed a deeper understanding of the concepts of gravity and momentum than the students in the control group. A delayed posttest indicated that the depth of understanding was retained for students in the experimental group, although it should be noted that students in the control group did not take the delayed posttest.

5. **Metacognitive skills are related to argumentation skills.** *Metacognition*, which has been described as thinking about thinking to improve one's thinking, has

been linked to critical thinking and conceptual change (Yore & Treagust, 2006). Mason and Santi (1994), who worked with 5th-grade students (ages 10 to 11) who were studying pollution, identified four levels of metacognitive awareness during argumentation: (1) awareness of what one knows, (2) awareness of why one knows something, (3) awareness of knowledge construction procedures, and (4) awareness of changes in one's own conceptual structures. They also found that specific elements of Toulmin's (1958) argument pattern were related to specific levels of metacognitive thinking—for example, students' use of warrants was related to an awareness of knowledge construction procedures. Duschl et al. (1999), who worked with middle school science students, also noted a connection between argumentation and metacognition and suggested that students' understanding of patterns of argument could be used to develop metacognition.

Suggestions for Future Research

Argumentation is a relatively recent focus in science education research, so there are many areas requiring further research. Questions that need to be addressed include the following: "Is the quality of argumentation determined by the presence of particular elements such as warrants and qualifiers or by the level of persuasiveness of the arguments?," "What influence do factors such as gender, power, and academic ability have on the quality of argumentation and on the extent of student participation?," "Is argumentation more appropriate for particular science topics, and, if so, which topics and at what grade levels?," "What do teachers require in the way of professional development, both preservice and inservice, in order to effectively implement argumentation?," "What role does metacognition play in argumentation?," "Are there tools other than TAP or Walton's presumptive reasoning scheme that may be more suitable for analyzing arguments and argumentation?," "Do students who possess skills in argumentation have a greater understanding of public science, the science presented in the media?," and "Is there a link between the use of argumentation and science understanding?" Addressing these final two questions is essential if argumentation is to become an integral part of the science curriculum and classroom practice.

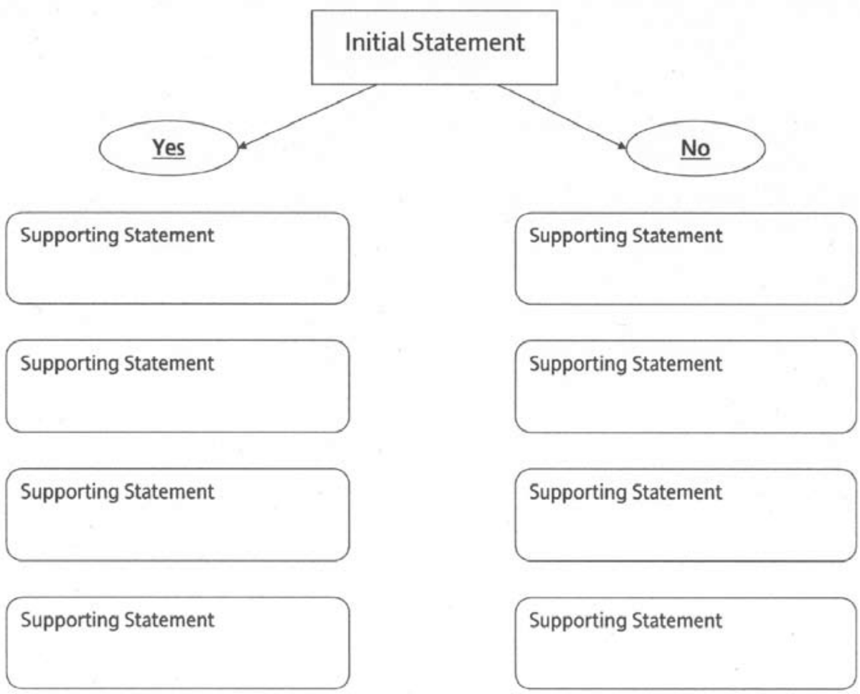
Implications for Teachers

The review of the science argumentation literature revealed some implications for classroom teachers, with two major issues: (1) professional development and (2) explicit teaching. Driver et al. (2000) called for a shift in emphasis from rhetorical arguments conducted by teachers to dialectical and analytical arguments conducted by students. Teaching professional development with an emphasis on pedagogical knowledge and pedagogical content knowledge would help teachers to negotiate this shift. Duschl and Osborne (2002) and Mercer et al. (2004) noted that teachers must establish norms for argumentation and explicitly teach argument skills. Professional development would benefit teachers who are attempting to modify their classroom practice to include a focus on argumentation.

The science argumentation literature contains many suggestions for instructional approaches that can be used to explicitly teach argumentation. Those approaches include using a discussion web to encourage students to develop supporting statements for both sides of an argument (see Figure 2) (Alvermann, 1991). Students also could use computer software to construct and edit arguments (e.g., *SenseMaker*, as described in Bell & Linn, 2000). Teachers could scaffold student argumentation using frameworks such as those developed by Osborne et al. (2004,

p. 1002). For example, teachers might present students with competing theories and ask them to provide evidence for the theory that they believe is correct. The structured controversy technique could also be used to scaffold argumentation and might be useful for explicit development of metacognitive skills (Johnson & Johnson, 1988). These instructional approaches share the following common feature: argumentation instruction is embedded within an authentic inquiry. Practicing argumentation skills within a meaningful context mitigates the transfer of problems encountered by many explicit instruction approaches.

Figure 2. Discussion Web Template—Given an Initial Statement, Students Develop Supporting Statements for Both "Yes" and "No" Positions.



Source: Alvermann (1991)

Concluding Remarks

Argumentation has been called the language of science, and it has been identified as a possible tool for promoting conceptual change (Driver et al., 1994; Duschl et al., 1999; Mercer et al., 2004; Nussbaum & Sinatra, 2003). Furthermore, argumentation is a critical component of scientific literacy (Jiménez-Aleixandre & Erduran, 2008). Although the use of argumentation needs to be more closely examined in future research, current indications are that teachers can effectively implement argumentation in the classroom, especially if they have received adequate professional development; students can improve their argumentation skills; argumentation and metacognition are closely related; and argumentation may lead to conceptual growth and change.

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