Images and implications of argumentation from science studies and the learning sciences for the practice of science education

Leah A. Bricker

Philip Bell

University of Washington

Final Manuscript Draft

FULL CITATION:

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education*, *92*(3), 473-498.

Images and implications of argumentation from science studies and the learning sciences for the practice of science education

Abstract: Argumentation has become an increasingly recognized focus for science instruction—as a learning process, as an outcome associated with the appropriation of scientific discourse, and as a window onto the epistemic work of science. Only a small set of theoretical images of argumentation have been deployed and investigated in science education, however, while a plethora of images have been developed in the interdisciplinary fields associated with science studies, the learning sciences, and other relevant fields. This paper attempts to review a range of such theoretical images of argumentation and discuss the possible implications for the orchestration of science education; the goal being that the science education research community might consider a broader range of forms and roles of argumentation in conjunction with the learning of science.

Images and implications of argumentation from science studies and the learning sciences for the practice of science education

Science educators now recognize the importance of engaging students of science in actual scientific practices, such as argumentation, explanation, and modeling (e.g., Duschl, Schweingruber, and Shouse, 2007). As a science education community, we argue that before we decide what theoretical images of these practices we wish to engage students of science with, which we will use as analytical lenses, and which we will utilize in the design of science learning environments, we need to look much more broadly at the images of these practices as they have been theorized in a range of relevant disciplines. Many of these theoretical images stem from disciplines that philosophize about the scientific enterprise and study scientific discourses and practices in situ. We argue that it is in our community's best interest to gather these various theoretical images of scientific practices and discourses and then engage in thorough and thoughtful dialogue about what theoretical images we wish to utilize in our research and practice.

In this paper, we provide an example of looking across disciplines in an effort to gather theoretical images of scientific practices and discourses in order to think about the implications for science education. We use the scientific practice of argumentation as our example although ours is a general point that applies to the range of epistemic practices of science (e.g., explanation, modeling). What follows is a review of theoretical images of argumentation that stem from formal logic, argumentation theory, science studies, and the learning sciences. To be clear, our project is not to provide a comprehensive review of the science education literature to date related to argumentation (see Erduran and

Jiménez-Aleixandre, 2007 for a more comprehensive review of this kind). Rather, we are interested in understanding how scholars from other disciplines have theorized about argumentation and which of these theoretical images might have purchase for research and practice in science education.

Rationale for Focusing on Argumentation

Argumentation is increasingly viewed as a leading instructional approach and educational goal for science education (e.g., Bell, 2004; Duschl, Schweingruber, and Shouse, 2007; Osborne, Erduran & Simon, 2004). One way of engaging young people with the workings of the scientific enterprise and granting them access to that enterprise is through argumentation because argumentation is a core epistemic practice in the sciences (e.g., Bell, 2004; Duschl and Grandy, 2004; Duschl, Schweingruber, and Shouse, 2007; Kelly and Bazerman, 2003; Toulmin, Rieke, Janik, 1984). Because argumentation is critical to producing, evaluating, and therefore, advancing scientific knowledge, it follows that it should be a core component of school science—as a way to help students engage with the social construction of scientific ideas as well as learn about the workings of the scientific enterprise (Bell, 2004; Bell and Linn, 2002). As justified by the goals of science education (American Association for the Advancement of Science/Project 2061, 1989, 1993; Duschl, Schweingruber, and Shouse, 2007; National Research Council, 1996; Osborne, Collins, Ratcliffe, Millar, and Duschl, 2003) it can be highly beneficial for students in science classrooms to learn how to identify and evaluate scientific arguments, as well as learn to how craft them.

Currently, this type of activity rarely takes place in school science (cf. Duschl, Schweingruber, and Shouse, 2007; Osborne, Collins, Ratcliffe, Millar, and Duschl, 2003). Schwab's (1962) historic critique of school science all-too-often taking the form of a “rhetoric of conclusions” (p. 24)—instruction that ignores the practices scientists use to construct, support, and evaluate claims—still rings true. This situation serves to portray scientific knowledge as objective and true, in a positivistic sense, versus portraying that knowledge as a series of claims evaluated by interpreting data and by impeaching alternative interpretations (see Norris and Phillips, 2004 for a fuller account). Besides overemphasizing the stability of scientific knowledge and the workings of the scientific enterprise to students, engaging young people with a rhetoric of conclusions may have other philosophical implications as well. One could argue that the very act of teaching nothing but conclusions might unwittingly convey a scientific realist position (cf. Kukla, 1998) and bar young people in science classes from considering alternative philosophical lenses on science, such as instrumentalism (cf. Stanford, 2006) or constructivism (cf. Barnes, Bloor, and Henry, 1996).

Some scholars are advocating for structuring science education through an argumentation frame in order to make young people’s science education experiences more representative of the very discipline those experiences purport to model (e.g., Bell, 1997, 2004; Kuhn, Kenyon & Reiser, 2006; Newton, Driver, and Osborne, 1999; Osborne, Erduran, and Simon, 2004; Sandoval, 2003). Teaching science through a focus on argumentation has been shown to foster scientific thinking (e.g., Koslowski, 1996; Kuhn, 1992, 1993) by helping young people wrestle with scientific ideas more effectively as they socially construct them. Numerous researchers have designed curricular interventions promoting argumentation and have fostered argumentation in science classrooms for these reasons. However, we believe more needs to be done.

As we argue in this article's introduction, in order to better understand the phenomenon of argumentation, as well as its role as a learning practice—all for the purpose of designing and engaging young people with more authentic scientific experiences in science classrooms and helping them learn—science educators could benefit from a broader consideration of theoretical images for argumentation published by scholars in fields including argumentation theory, science studies, and the learning sciences.

Insert Figure 1 about here

To summarize our view of the theoretical situation, we have created the heuristic representation shown in Figure 1. This heuristic shows the intersections between science education research focusing on argumentation and the disciplines from which we have culled the various theoretical images of argumentation we highlight in this article. Within the intersections, we have called out specific lines of work from specific disciplines that have informed research in science education. This heuristic helps us make two claims: (a) we argue that there is not as much overlap between the science education enterprise and the theoretical work found in disciplines from science studies and the learning sciences as there should be, and (b) we argue that science education research and practice related to argumentation has failed to account for learners' everyday argumentative practices and/or for the social (e.g., Cetina, 1999; Kuhn, 1962; Longino, 1990) and inscriptional (e.g., Latour and Woolgar, 1979/1986) aspects of argumentation found in professional scientific practice. We discuss the implications of these oversights later in the article.

Theoretical Images of Argumentation

We now turn to our explication of various theoretical images of argumentation. Given that we could not hope to review an exhaustive list of relevant literatures within each of our categories, we had to make choices about which theoretical images to highlight. We have selected theoretical images within each category based on the contribution they have made to the discipline within which they are situated. We have also selected these theoretical images because we believe they offer insights for science education, which we discuss in detail throughout. After detailing these theoretical images and their implications for science education, we briefly discuss our on-going research, which examines the argumentation understandings and competencies of young people in their everyday lives. Lastly, we revisit our main argument in hopes of starting a conversation in science education about the purchase these various theoretical images of argumentation may have relative to the field's analytic and design efforts.

Theoretical Images of Argumentation from Formal Logic

For many the gold standard, so to speak, of argumentation is formal logic. Blackburn (1994) in *The Oxford Dictionary of Philosophy*, defines argument as follows:

> To argue is to produce considerations designed to support a conclusion. An argument is either the process of doing this (in which sense an argument may be heated or protracted) or the product, i.e. the set of propositions adduced (the premises), the pattern of inference and the conclusion reached. An argument may be deductively valid, in which case

> the conclusion follows from the premises, or it may be persuasive in other ways. Logic is the study of valid and invalid forms of argument. (p. 23)

Blackburn considers an argument the "product" of "producing considerations designed to support a conclusion." He states that this "may be deductively valid" and that "logic is the study of valid and invalid forms of argument." In this section, we concentrate on clarifying these pieces of his definition.

Formal logic is often traced to the Greek conception of *Logos* or logical argument. Kennedy (1991), in the introduction to his translation of Aristotle's *On Rhetoric*, describes Aristotle as "the inventor of formal logic" (p. 4). However Toulmin (1958/2003) and others including Kennedy himself paint a picture of a pragmatic Aristotle, someone who believed in applying logical argument to real-world situations. Instead, the Platonic tradition, given new life by Ŕene Descartes, is ultimately responsible for the version of formal logic that persists today (e.g., Perelman and Olbrechts-Tyteca, 1969; Toulmin, 1958/2003). This is an image of logic (and by association, argumentation) as syllogism; a statement with major and minor premises and a conclusion, which necessarily follows from the premises. An example of a syllogism is: All snakes are reptiles. All reptiles are cold-blooded. Therefore, all snakes are cold-blooded. Arguing successfully from premise to conclusion has "…nothing to do with being right" (Lemke, 1990, p. 122). The validity of an argument is judged solely on whether one produces the correct syllogistic form in accordance with the governing rules of formal logic.

Many scholars (e.g., Perelman and Olbrechts-Tyteca, 1969; Toulmin, 1958/2003; van Eemeren, Grootendorst, and Snoeck Henkemans, 2002; van Eemeren and

Grootendorst, 2004) argue against solely applying this syllogistic notion of logic to the study of argumentation because they believe it does not capture elements of everyday argumentation, which we claim includes scientific argumentation because of the social nature of scientific practice. These scholars claim that argumentation studies should be grounded in the practical uses of argumentation versus in the "…abstract 'argument forms'…in which a conclusion is derived from a set of premises [and] the main point…is how to distinguish between 'formally valid' argument forms and argument forms that are not formally valid" (van Eemeren, Grootendorst, and Snoeck Henkemans, 2002, p. xii).

Looking at our heuristic, readers will see that the only theoretical image of formal logic we see intersecting with science education is the image those constructing high stakes accountability systems utilize in some instances as a model for item development. Given the objections to examining argumentation through a formal logic lens, we reject this theoretical image as helpful in engaging students of science with what it means to argue scientifically. In other words, we do not believe our mission in science education relative to argumentation involves teaching students of science how to form syllogisms. We turn now to what we believe are more helpful theoretical images of argumentation for science education.

Theoretical Images of Argumentation from Argumentation Theory

We begin this section with a few select works by van Eemeren and colleagues. They provide definitions for terms, such as "argumentation," "rational," and "reasonable," which are important to this survey of theoretical images of argumentation. van Eemeren and Grootendorst (2004) define argumentation as "…a verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint" (p. 1).

Argumentation is "verbal" in that one uses spoken and/or written language to produce it (although others would disagree and we expand on their positions later in this section). Argumentation is "social" because it usually involves two or more people (although they acknowledge internal argumentation, which can be viewed as social using Vygotsky's [1978] conceptualization of internalization of external social forms). Argumentation is "rational" in that "it is aimed at defending a standpoint in such a way that it becomes acceptable to a critic who takes a reasonable attitude" (van Eemeren, Grootendorst, and Snoeck Henkemans, 2002, p. xi). van Eemeren and Grootendorst expand on their definitions of "rational" and "reasonable," describing them as "the use of the faculty of reasoning" and "the *sound* use of the faculty of reasoning" (p. 124 – emphasis in the original) respectively.

van Eemeren and colleagues discuss their concept of reasonableness at length and differentiate their meaning of reasonable from Perelman and Olbrechts-Tyteca's meaning of the concept, as well as from Toulmin's (whose work we will discuss in greater detail in the next section). The distinction they make is in relation to the question, "Reasonable to whom?" van Eemeren and colleagues claim that following Toulmin's work (1976) there are three perspectives one can take when responding to that question. The first is the perspective of formal logic (as summarized above), which states that an argument is reasonable if it follows the correct form in which the conclusion necessarily follows from the premises. As already discussed, this is not a perspective that van Eemeren and colleagues (and many others) are willing to adopt.

The two other perspectives are "anthropologico-relativistic" (van Eemeren and Grootendorst, 2004, p. 15) and "critical-rationalistic" (p. 17). The purpose of argumentation situated in the former perspective is to persuade others and therefore, reasonableness is judged by those who the arguer is trying to persuade. van Eemeren and colleagues situate Toulmin and Perelman and Olbrecths-Tyteca's positions on reasonableness in perspective, although they acknowledge differences in these scholars' work with respect to this issue. For example, for Perelman and Olbrechts-Tyteca, reasonableness is judged by the target audience (Perelman and Olbrechts-Tyteca, 1969; van Eemeren and Grootendorst, 2004). However for Toulmin, reasonableness is judged against criteria specific to specific groups of people, such as lawyers and scientists. In other words, argumentation is field-dependent (Toulmin, 1958/2003; Toulmin, Rieke, and Janik, 1984; van Eemeren and Grootendorst, 2004). One could argue that Perelman and Olbrechts-Tyteca and Toulmin's positions are not far apart given that they both consider the target audience crucial in judging the reasonableness of arguments and given that one would assume an audience in Perelman and Olbrechts-Tyteca's sense would have some sort of evaluation criteria, akin to that of scientists for example, even if implicit.

The purpose of argumentation situated in the critical-rationalistic perspective is to resolve differences of opinion. "The reasonableness of the procedure [van Eemeren and colleagues' Pragma-dialectical approach] is derived from the possibility it creates to resolve differences of opinion (its *problem validity*) in combination with its acceptability to the discussants (its *conventional validity*)" (p. 132 – emphasis in the original). In this way, van Eemeren and colleagues call for analyses of argumentation that are both normative and descriptive.

Returning now to van Eemeren and colleagues' definition of argumentation, another important aspect of the definition is the notion of "standpoint." Those arguing have a position about whatever the subject is that is being argued. van Eemeren and colleagues draw a distinction between argumentation and other forms of discourse, such as explanation, elaboration, and clarification and the distinction rests on the notion of standpoint. They claim that explanations, elaborations, and clarifications are used when discussing matters that are already accepted, whereas argumentation is "always brought to bear on a standpoint that has not yet been accepted" (van Eemeren, Grootendorst, and Snoeck Henkemans, 2002, p. 43). Not everyone agrees with their distinction, however. Simosi (2003) brings another perspective to bear by claiming that argumentation is prominent in people's explanations and therefore, explanations have argumentative properties. For example, people often justify why their explanation should be counted as the correct explanation as opposed to possible alternative explanations.

Lastly, this group has much to say about the purposes of argumentation, which they see as a process of convincing "a reasonable critic of the acceptability of a standpoint" (van Eemeren, Grootendorst, and Snoeck Henkemans, 2002, p. xii) by justifying that standpoint with various propositions. This is in service of utilizing argumentation to settle differences of opinion, which they believe is different from models of argumentation that focus on persuasion, justification, and winning as their purposes (although we see elements of the first two purposes in their stated purposes). For van Eemeren and colleagues, the aim of argumentation "is not to maximize agreement but to test contested standpoints as critically as possible by means of a systematic critical discussion of whether or not they are tenable" (van Eemeren and

Grootendorst, 2004, p. 188). They align themselves with the classical tradition, taken from Plato and Socrates, of a dialogic approach to argumentation, but unlike Plato and Socrates' use of this method to try and arrive at the ultimate Truth, van Eemeren and colleagues steer toward Aristotle's use of the method to attempt to change people's minds by convincing them to accept standpoints not yet accepted, hence the *pragma*, for pragmatic, in their conception of dialectic.

We return now to van Eemeren and colleagues' notion of argumentation as a verbal activity (spoken and written word). Another group of scholars (e.g., Groarke, 1996; Slade, 2003) rejects an image of argumentation as always verbal and claims that argumentation can be represented visually as well, either with or without accompanying text. For example, Slade (2003) analyzes advertisements and claims that often times, arguments are contained within visual structures of the advertisements. Slade uses this viewpoint to critique a notion of rationality as purely a product of the written word. She notes that "being reasonable is fundamentally a feature of discourse and action, not of written linear texts" (p. 151). Groarke (1996) in his analyses of many types of images (e.g., political cartoons, advertisements, classical works of art) also argues against a verbal account of reasoning and rationality. He believes that expanding definitions of argumentation to include the visual greatly strengthens analytic attempts to "…explain and assess ordinary reasoning…for visual components play a pivotal role in many attempts to prove, convince or persuade" (p. 105).

Implications for science education.

As readers can see from our heuristic representation in Figure 1, we believe that although science education has been informed by the theorizing of argumentation scholars, the link is quite implicit. Granted, Toulmin's micro-structural analysis of argumentation (which we discuss in detail in the next section) is widely used in science education but it is unclear how many in science education have read Toulmin's work in relation to the other argumentation theorists we mention in order to understand how their conversations with each other are situated in a larger theoretical framing of argument. Doing this theoretical work is important for the design and analysis of science learning environments that incorporate argumentation because it allows designers and analysts to think critically about which theoretical image(s) of argumentation they are utilizing in their designs and analyses (and to what ends) and therefore, which images they are ultimately holding up to students of science as images of scientific argumentation.

There appear to be three issues raised by our discussion of theoretical images of argumentation from argumentation theory. The first involves the notion of standpoint. From our vantage point from within the science education community, it seems that science education scholars count various practices as argumentation. If we accept that argumentation must involve a standpoint, is explanation argument? Is question posing and answering argument? As a field, we should be clear about our definitions of "argument," "argumentation," "reasonable," and "rational," for example, and we argue that argumentation theorists can be quite helpful in this regard.[1]

A second and related issue involves the notion of purpose. For what purpose do we wish students of science to engage in scientific argumentation? This is related to which theoretical images of scientific argumentation we wish to engage students with.

[1] Although we do not have the space to engage with their text here, we encourage readers to consult Toulmin, Rieke, and Janik (1984) for additional definitions of "argument," "argumentation," "rationality," and "reasoning."

For example, as a field, we should discuss whether to incorporate athropologico-relativistic and/or critical-rationalistic images of argumentation into our designs and analytic frameworks based on our purposes and we should discuss whether we wish to undergird our designs and analytical approaches with philosophies associated with dialectic or pragma-dialectic approaches.

A third issue that is applicable relates to the discussion of non-verbal modes of argumentation. Lemke (1998) claims that scientists to do not solely construct their arguments verbally. Instead, they use a semiotic combination of text, mathematical expressions, diagrams, photographs, etc. Lemke also claims that visual images in scientific texts, such as diagrams, photographs, and graphs, do not simply restate the meaning of the written words. Readers of scientific text must interpret the entire document, including words, visual images, and reference lists, for example, to comprehend the arguments being made. In science education, we need to think critically about how to bring students of science into this more comprehensive view of scientific argumentation. What other theoretical images of scientific argumentation do we wish to engage students of science with and incorporate into our designs and analytic frameworks? We present additional images of argumentation for consideration in the next section.

Theoretical Images of Argumentation from Science Studies

Science studies is an interdisciplinary field comprised of scholars from philosophy, anthropology, rhetoric, history, and sociology, who are interested in studying the processes and products of science, as well as the scientists engaged in this work. Sismondo (2004) summarizes some claims that the science studies field makes:

> S&TS [science and technology studies] starts from an assumption that science and technology are thoroughly social activities…there is no abstract and logical scientific method apart from the actions of scientists and engineers…*scientists and engineers are always in the position of having to convince their peers and others of the value of their favorite ideas and plans* – they are constantly engaged in struggles to gain resources and to promote their views…ideology and values of many different types are important components of research. Even conflicts in a wider society may be mirrored by and connected to conflicts within science and technology; for example, splits along gender, race, class, and national lines can occur both within science and in the relations between scientists and non-scientists (p. 10 – emphasis added).

In this section, we examine some of the theoretical images of argumentation found within the science studies literature.

Theoretical images of argumentation from philosophy of science.

Although one might quibble with Pera (1994), a philosopher of science, about his empirical realist positions, he argues to others in his field that images of science must be changed from those of "science as demonstration" (p. 2) and method (the Cartesian project) to those of science as argumentation. His aim is "to build the missing bridge between persuasion and scientific knowledge" (p. 11), which he claims is possible through scientific debate ("dialectics," p. ix). Scientific debate has three key participants; "a proposer who asks questions, nature that answers, and a community of competent interlocutors which, after a debate hinging on various factors, comes to an agreement upon what is to be taken as nature's official voice" (p. 11). Pera stresses however that "nature reacts to cross examination" (p. ix) so the process is not impartial. He also stresses that in order to know something, the community has to come to consensus on "nature's correct answer" (p. ix). Pera is cognizant of the fact that this conception might signal relativism to some but he says this is not the case because "agreement among the members of a community is not merely conversational; it is constrained, although not imposed or dictated, by nature" (ix).

As previously seen in the works of others writing about scientific discourse, he argues that context is critical to understanding an argument. He states that "in order to ascertain the right logic for an argument, an analysis of its structure is not enough. Only context can provide the necessary information" (p. 109). Pera claims that the purpose of argumentation can only be understood in relation to the context in which the argumentation is situated. Toulmin, to whom we now turn, would agree, although his work has been misused by others in this regard.

Within analytic philosophy, Toulmin has provided a micro-structural image of argumentation. His ideas have been adopted by many scholars in a variety of disciplines (including a number of scholars in science education), although he developed his ideas originally in the context of legal argumentation. Toulmin himself has said that he never intended to create a generic structural analytic framework (1958/2003, vii). Instead he meant to critique formal logic and offer an alternative image of argumentation. Nonetheless, his ideas have become known as the "Toulmin Model" and it consists of the following conceptual pieces: claims, grounds (evidence), warrants (justifications for moving from specific grounds to specific claims), backings (more general reasons for warrants' authority), modal qualifiers (e.g., usually, possibly, certainly, necessarily), and possible rebuttals to conclusions.

Toulmin’s structural framework is seen as an analytic framework and tool for evaluating the strength or weaknesses of arguments (e.g., Bell and Linn, 2000). Examining the structural aspects of arguments does not signify that Toulmin embraces an image of argument and argumentation as decontextualized—as we have noted, a typical misstep when his model is used as an analytical / evaluative frame (e.g., when comparisons are made between arguments constructed for different purposes or under different evaluative expectations). Far from it, Toulmin charges that formal logic has perpetuated a decontextualized image of argument and argumentation and he seeks to correct that image through his structural accounting. Like Pera, Toulmin calls for images of argumentation that are somewhat situated. The context in which argumentation is embedded is important to consider because it will determine whether or not arguments put forth are judged as reasonable. Toulmin states:

> Arguments within any field can be judged by standards appropriate within that field, and some will fall short; but it must be expected that the standards will be field-dependent, and that the merits to be demanded of an argument in one field will be found to be absent (in the nature of things) from entirely meritorious arguments in another (1958/2003, p. 235).

Toulmin proposes the need for empirical work to help collect various forms of argumentation from different fields. These studies should highlight not only the forms of argumentation found but also how argumentation functions within these various fields.

Toulmin states that historical and anthropological considerations must be brought to bear in these studies because he believes this interdisciplinary approach will help appropriately contextualize argumentation.

Although Toulmin developed his ideas in order to view everyday argumentation as logical and rational given the context in which it is embedded, some using Toulmin's ideas have often concluded exactly the opposite (i.e., that everyday argumentation is illogical and/or irrational) because various pieces of Toulmin's scheme are missing in the argumentation they analyzed. However, Simosi (2003) proposes that the absence of some of the Toulmin's structural components in everyday argumentation is to be expected. "These elements may be missing because the arguer considers them to be well-known—or assumed—by his interlocutor, and, thus, he does not regard it necessary to refer to them explicitly in his attempt to persuade the other" (p. 188). Like Toulmin, she makes a case for why argumentation analyses must consider the context in which the argumentation is embedded.

Toulmin, Rieke, and Janik (1984) outline two types of scientific arguments—regular and critical. Toulmin and colleagues state that "in regular arguments, the goal of reasoning is to establish a factual conclusion by appealing to currently accepted scientific ideas (p. 333). Critical arguments on the other hand are those employed "when scientists challenge the credentials of current ideas" (p. 332). Toulmin and colleagues claim that scientific arguments "involve no real conflicts of interest, nor are there any permanent winners of losers as a result of their resolution" (p. 345). In this perspective, having a personal stake in one's work is not at issue because scientists argue solely to build sound theories for the collective good of the enterprise. As we shall see, other studies of science might disagree with the notion that scientists do not have a personal stake in their work given the social nature of the enterprise.

Theoretical images of argumentation from the history, anthropology, and sociology of science.

Many scholars employ elements of historical, anthropological, and sociological methods when studying science. Barnes, Bloor, and Henry's (1996) discussion of the sociology of science describes the science studies project in general:

> The objective of the sociology of science [and many other disciplines under the science studies umbrella] is to describe scientific research as action, and to understand scientific knowledge as implicated in and produced by that action. Scientific research is what scientists collectively do; sociology is concerned with what people collectively do, with how and why they do it, and with what consequence…it reveals the limitations of existing stereotypes of science, stereotypes which are relied upon as we orient ourselves to scientists and the claims they make upon us, but which are *not* derived from detailed familiarity with what scientists actually do (p. 110 – emphasis in the original).

What projects, relative to scientific argumentation fall within these confines? Studies of scientific controversies, for example—including those focused on scientific knowledge claims as well as those that are science-based social or policy-related disputes (cf. Brante, 1993) – provide one fruitful avenue for studying scientific argumentation. As Sismondo states, "Studies of scientific controversies show how people can give meaning to information and how they sometimes convince members of a community to agree with that meaning" (p. 107). One of the central aims of scientific activity is to establish facts about the natural world. Science study scholars consider moments of scientific controversy important because it is during controversy one can examine knowledge construction in process, which is hard to do once scientific knowledge has been "black boxed." Black boxing is a term used to indicate that scientific facts are accepted. At that point "the history and grounds of their becoming good facts or successful facts is seen as unimportant to their use" (p. 97).

Controversial periods in science provide those who study science with information about the histories and grounds of fact construction because it is during controversial times that "participants often make claims about the stakes, strategies, weaknesses, and resources of their opponents" (p. 100). Also, by studying controversial periods, researchers are privy to the resources scientists utilize to convince others in their field. An example of one such controversial period is documented in the debates surrounding the announcement, in 1989, by two scientists, who claimed to have observed cold fusion. Collins and Pinch (1993) and Gieryn (1992) used accounts of these debates in part “to illustrate how the controversy was resolved without ironclad proofs or refutations” (Sismondo, 2004, p. 100).

As foreshadowed by the last quotation, studies of scientific controversies also pay attention to how controversies are resolved (Collins & Pinch, 1993). Sometimes they are resolved by interlocutors effectively utilizing strategies to question their opponent’s methods, results, or theoretical framework. Sometimes appeals to scientific norms or reputation can be enough to legitimize or deligitimize scientific claims, and thus end controversies. "Sometimes one idea will become dominant because many researchers can see how to use it, how to build on it, regardless of its validity" (Sismondo, 2004, p. 106). In this case, controversy is resolved because of the instrumentality of work rather than the truth-value associated with claims.

Studies of scientific laboratories provide another rich arena for the study of scientific argumentation. For example, Latour and Woolgar (1979/1986) designed a classification system to account for the different types of statements found in scientific papers. Type 5 statements, for example, denote "a taken-for-granted fact" (p. 76) and contain no clarification verbiage because it is assumed that everyone understands these statements. Teaching texts (e.g., textbooks) contain type 4 statements, which denote explicitly framed relationships between entities. Type 3 statements contain modalities (e.g., ‘generally assumed,’ ‘possibly’), creating the impression that these statements are less certain. Scientific review articles contain type 3 statements. Type 2 statements contain more modal qualifiers and seem more claim-like than fact-like. These types of statements are found more often in drafts explicating research that are being circulated in the laboratory. Statements of this type often contain "tentative suggestions, usually oriented to further investigations..." (p. 79). Lastly, type 1 statements contain actual speculations and these are used only in one on one discussions or at the very end of papers.

Using this classification scheme, Latour and Woolgar conceptualized scientific practice as a means of changing statement types from one to the other. The goal is to create as many type 4 statements as possible in the face of a variety of pressures to submerge assertions in modalities such that they became artifacts. In short, the objective is to persuade colleagues that they should drop all modalities used in relation to a particular assertion and that they should accept and borrow this assertion as an established matter of fact, preferably by citing the paper in which it appeared (p. 81).

Latour and Woolgar claim that scientists in the laboratory are expressly aware of how their own assertions are being utilized by others (e.g., rejected, quoted). Instead of being mere scientists, Latour and Woolgar argue that scientists are "writers and readers in the business of being convinced and convincing others" (p. 88) and laboratory practice can be seen as "persuasion through literary inscription" (p. 88).

Rhetorical analysis of scientific argumentation.

Discussion of inscription leads nicely into theoretical images of argumentation from the rhetoric of science, which is another field that is at times situated under the science studies umbrella. Rhetoricians of science study scientific speech and writing. Scientific journal articles, for example, are sources for the examination of the rhetorical resources scientists use to persuade their audiences (Bazerman, 1988). However, scientists also attempt to convince each other through more informal communication channels, such as phone calls, emails, and face-to-face informal interactions (e.g., shared dinners at conferences or over drinks).

Sismondo (2004) claims that "rhetoric always mediates material actions like experiments and observations" (p. 101). Research is designed with an eye toward convincing others. Scientists employ different methods when attempting to convince others. For example, appeals can be made to the notion of what science is and what makes good science. In other words, scientists can convince by claiming that their work is *more scientific* than the work of their colleagues. Scientists can also appeal to reputation. If a researcher is seen as brilliant and has a record of producing acceptable results for example, s/he is more likely to be believed. Scientists also appeal to norms of scientific behavior, such as skepticism and a de-coupling of personal values and beliefs from experimental method and results. In the end, "scientific writing, like most other writing, is constructed to have effects, and when it is carefully done all of its elements contribute to those effects" (p. 102).

Unlike Sismondo's characterization of scientific argumentation as scientists persuading their "core set" (other scientists within the same discipline whose allegiances matter most) about the merits of their empirical work, Ceccarelli (2001) presents the cases of three scientists who argued for cross-disciplinary work and the creation of new fields. Ceccarelli conducts close textual analyses of these scientists' writing in order to examine what specific rhetorical devices and strategies the scientists used to attempt to persuade their intended audiences. She claims that simply focusing on scientific facts or truth claims creates an image of science as a "purely cognitive enterprise" (p. 169). By examining the processes and resources scientists use to persuade, Ceccarelli paints scientific knowledge construction as social as well as cognitive.

Ceccarelli introduces two examples of strategies that she determines Dobzhansky and Schrödinger, two of the scientists she profiles, effectively use to bridge disciplinary boundaries. One strategy is the "conceptual chiasmus" defined as "…a rhetorical strategy that reverses disciplinary expectations surrounding conceptual categories, often through metaphor, to promote the parallel crisscrossing of intellectual space" (p. 5). This strategy uses discourse to enable scientists in one field to imagine an issue in ways employed by scientists in another field and vice versa. For example, in her analysis of Dobzhansky's text, Ceccarelli finds that he uses the metaphor of a topographic map to enable biologists and naturalists, representatives of the two fields involved in this historical event, to envision their own work utilizing the framework of the other's work. Using Galison's (1997) notion of a trading zone, the conceptual chiasmus seems to be one avenue through which two disciplines can trade and once the two disciplines are trading, there is a better chance that they will be persuaded to accept the necessity of interdisciplinary work and ultimately a new hybrid field (which was Dobzhansky's intent).

Another rhetorical strategy Ceccarelli draws attention to is the "polysemous textual construction," which "is a passage that can be read (that is, interpreted) in two or more ways" (p. 5). Ceccarelli claims that this strategy is useful in ensuring that different audiences will accept the same message, even given their different interpretations. Turning again to Dobzhansky, Ceccarelli claims that his "discussion of genetic drift was polysemous" (p. 50) because both geneticists and naturalists could use the concept of genetic drift to justify their own work. The key here seems to be that both groups could think about their different work through the lens of the same concept. Through Ceccarelli's analyses, one can see the importance of studying rhetorical strategies used in arguments and argumentation and the overall purpose the author(s) has for using these strategies. She notes that examining the "rhetorical form and function of influential scientific texts has something important to contribute to our understanding of how science develops" (p. 177).

Fahnestock (1986) describes the rhetorical moves that popular writers of science use to present scientific findings to lay audiences. Her comments about the centrality of purpose, context, and audience in argumentation echo those made by others whose work we have surveyed in this article. In discussing purpose, Fahnestock highlights the difference between scientific and popular science writing. Fahnestock claims that scientific texts are forensic in nature because they are "explicitly devoted only to arguing for the occurrence of a past fact; significance is largely understood" (p. 278), whereas popular science writings are epideictic in nature because "their main purpose is to celebrate rather than validate" (p. 279). Given their purpose, authors select rhetorical strategies that will ultimately persuade their audiences and thereby achieve their goals.

Fahnestock also highlights the importance of context, saying that it is context, rather than actual wording, which determines with what degree of certainty an audience accepts a statement. As an example she shows how hedging, a rhetorical device which typically signifies possible uncertainty, is not read as such in particular contexts. Fahnestock uses the example of Watson and Crick's famous hedge, "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material" (Watson and Crick, 1953, p. 737) to make her point. Because the intended audience understood the significance of Watson and Crick's work, the "possible" was almost certainly not read and understood as a hedge. Lastly, Fahnestock highlights the importance of audience when considering issues of argument and argumentation. She says that "people inevitably have to be convinced that a situation exists before they ask what caused it or move on to decisions about whether the situation is good or bad and what should be done about it and by whom" (p. 290).

In her book *Rhetorical Figures in Science* (1999), Fahnestock examines certain figures of speech (e.g., antithesis, incrementum and gradatio, antimetabole, and ploche and polyptoton) that are prominent in scientific texts and shows how those figures function as rhetorical strategies. She claims that far from being ornamentation, figures of speech can be used to embody expanded arguments; "The figure…is a verbal summary that epitomizes a line of reasoning" (p. 24). She argues, as do other scholars highlighted in this survey that "language does do much of our thinking for us…" (p. xi). In order to understand one's thought processes, it is imperative that we examine discourse, whether it is written, verbal, or visual. Fahnestock notes that figures of speech can be presented visually and that in science, "visual modes of argument are preferred" (p. 42). This is similar to Lemke's (1998) claim that scientists do not solely argue verbally but rather "they combine, interconnect, and integrate verbal text with mathematical expressions, quantitative graphs, information tables, abstract diagrams, maps, drawings, [and] photographs…" (p. 4).

Fahnestock claims that it is not enough to identify the types of figures utilized in discourse. One must also pay attention to what work the figures are doing rhetorically. For example, Fahnestock examines antithesis (arguing from opposites) and claims that authors utilize this figure in three distinct ways: 1) employing it to highlight opposites already accepted as such by the given audience, 2) employing it to persuade the audience to accept a pair as opposites by promoting one part of a pair in opposition to the other, or 3) employing it to rework an existing oppositional structure. Fahnestock points to images of male and female brains used in some scientific texts in order to highlight the use of both verbal and visual antithesis in equating male with spatial and female with verbal.

Prelli (1989) too espouses the view that "science has an other-than-formally logical 'face" (p. 3). He claims that doing science "entails making arguments that are informal, material, contextual, and controversial" (p. 5). Prelli insists that context and audience matter when examining what a community counts as reasonable, which he believes is socioculturally and historically situated. Standards of reasonableness (versus the truth of argument) determine how arguments are critiqued and evaluated, as well as what community members will count as claims in the first place. Standards of reasonableness can change over time but "because they are shared standards, they also have considerable stability, solidity, and endurance" (p. 31).

Like others highlighted in this survey, Prelli notes that argumentation must be directed toward a purpose but for Prelli, the purpose is the audience's purpose (versus the rhetor's). For example, Prelli utilizes the notion of a "teacher-rhetor" (p. 41) when he discusses connections between argumentation and learning. Prelli uses the concept of utilizing prior knowledge as a learning mechanism when he claims that a successful rhetor understands that learning is an interaction and that his/her audience must clearly see connections between the argument being put forth and their existing understandings.

Implications for science education.

We draw readers back to our heuristic to claim that in science education, Toulmin's model for argumentation has been the most widely utilized theoretical image of argumentation. A small handful of science education scholars have employed theoretical images from rhetorical traditions as well (e.g., Kelly & Bazerman, 2003). We argue that science educators should take much greater advantage of the science studies literature with respect to engaging students of science with what it means to argue scientifically.

As we have noted in our heuristic representation, understanding the social and material practices in the sciences seems critical to science education research and practice but we are not at all certain how these types of images are being utilized in science education if in fact they are utilized. Many of us in science education cannot presume to know how scientists argue, for example, or where they argue, why they argue, and who exactly they argue with unless we enter scientific spaces ourselves (a science education research agenda that we believe is lacking) or use the science studies literature as a proxy. Either way, it is important for us as science educators to do our homework, so to speak, so that we can have thoughtful and rich discussions about what theoretical images of scientific argumentation we wish to engage students of science with and for what purposes.

Relative to purpose, at times it seems that there is a mismatch between the type of scientific argumentation being cultivated in science classrooms and the actual activity in which students of science are engaged. For example, students might be engaged in tentative knowledge construction but are expected to produce written scientific arguments that mirror those found in scientific journals. We should take more care in relating more comparable social spheres of scientists and children and a first step in this direction is understanding the various types and forms of argumentation scientists use, when they use them, and for what purposes.

One striking commonality among the theoretical images of argumentation in science studies is the importance of context and audience. If our designed learning environments in science education ask students to coordinate evidence with theory for example, is that enough? Should we be engaging students in conversations about what data and ultimately what evidences are appropriate given what scientific context they're operating in? When asking students of science to argue scientifically, should we be asking them to consider their audience(s)?

Lastly, theoretical images of argumentation from the science studies literature gives us tools we may wish to employ in the design and analysis of science learning environments. For example, we might consider engaging students of science with some of the rhetorical figures and how they are best employed in scientific argumentation given context and audience. Depending on our purposes, we might consider engaging students of science with studies of scientific controversies in order to engage them in conversations of how to argue scientifically. Another tool we might consider stems from Latour and Woolgar's inscription framework. Might it be instructive to teach students of science how to hedge and for what purposes, or how to convince their peers to allow them *not* to hedge their claims? It seems that doing so will not only make them more effective arguers but it will also make them more savvy consumers of scientific writing, one goal of the scientific literacy movement (cf. AAAS, 1989; Roth and Barton, 2004).

Theoretical images of argumentation in the learning sciences

We use Prelli's comments about learning as a segue into theoretical images of argumentation from the learning sciences—an interdisciplinary field that investigates learning from the disciplinary perspectives of psychology, anthropology, micro-sociology, applied linguistics, neuroscience, and computer science. In this next section we specifically focus on theoretical images of argumentation from ethnographic research and from cognitive psychology. We categorize theoretical images of argumentation from ethnographic research and cognitive psychology under the auspices of the learning sciences because findings from these literatures shed light on argumentation as a learning practice.

Ethnographic studies of argumentation.

Toulmin highlights the sociocultural nature of argumentation (Toulmin, 1958/2003; Andrews, 2005; Prior, 2005) but as we have argued that central piece of his theory seems to have gotten lost and instead, the 'Toulmin Model' has been reified and applied liberally "as a general heuristic" (Prior, 2005). As stated above, Toulmin himself calls for empirical studies of argumentation, including historical and anthropologic accounts. Others, such as Andrews (2005), agree and claim that ethnographic studies, for example, will provide better understanding of how argumentation is used in everyday life. In this section, we survey some ethnographic studies examining argumentation. We utilize the work of scholars including Corsaro (2003), Goodwin and Goodwin (1987), Kyratzis (2004), Ochs, Taylor, Rudolph, and Smith (1992), and Sarangapani (2003).

Many of the ethnographic accounts of argumentation focus on structural aspects of people's argumentation, purposes for argumentation in people's everyday lives, and how context enables and/or constrains argumentation practices. For example, Corsaro (2003) studies preschool children in three preschools: middle/upper middle class in California, Head Start in Indiana, and in Italy. He finds that preschool children are adept at forming arguments and engaging in argumentation. However, at the middle/upper middle class preschool, adults are quick to squelch argumentation because they view it as a negative practice. Corsaro disagrees and says that argumentation plays a critical role in children's peer culture, contributing "to the social organization of peer groups, the development and strengthening of friendship bonds, the reaffirmation of cultural values, and the individual development and display of self" (p. 162).

In the Head Start preschool and the Italian preschool, adults were much less concerned when children argued and did not immediately stop the activity. Corsaro finds that in these cases, the children's argumentation tends to be complex and extended. In fact, argumentation taking place between small numbers of children often expands to include more children and turns into extended group debates, where "highly complex negotiated settlements occur" (p. 162). Preschoolers in the Head Start school use intricate linguistic forms, such as oppositional talk, which is talk created to stand in opposition to what another party has just said and thus provides an opportunity to "test or realign the current arrangement of social identifies among [children's] peers…" (Goodwin and Goodwin, 1987, p. 205). Corsaro notes that in Italy, students' argumentation style is seen as more important than the eventual outcome of the argument. For example, Italian preschool children engage in "discussione" (p. 180) and employ the "cantilena [which] is a tonal device or sing-song chant…" (p. 187). Children have to fit the content of the discussione "into the structural demands of the *cantilena*" (p. 187 – emphasis in original) and those who are most gifted in doing so win the respect of their peers.

Kyratzis (2004) reviews the literature on peer culture and the utility of language in constructing and sustaining that culture. She includes a section in her review on conflict in peer culture and agrees with many of the arguments Corsaro makes in his work, including the claim that argumentation functions as a process to negotiate and renegotiate peer group social status. She highlights forms of argumentation in children's culture, such as "gossip talk, teasing, and conflict in games…" (p. 631). Much of the literature that Kryatzis reviews makes a case for argumentation as a device to learn "communicative competence" (p.634) where the definition of competence is dependent on broader cultural norms, as in the case of the Italian discussione, and on peer culture norms and rules, as in the case of game playing (e.g., kickball and hopscotch). Children determine, within the spaces in which they are situated, what constitutes competence and this notion is continuously negotiated. Kyratzis states that "communicative competence can be seen in the grammatical marking of conflict moves" (p. 634).

In their chapter *Children's Arguing*, Goodwin and Goodwin (1987) highlight some of these grammatical markings or linguistic features of children's argument. By doing so, they look at how argumentation is sustained in children's culture rather than how settlements occur. Marjorie Harness Goodwin collected data by audio recording the conversations of "working class black preadolescent girls and boys from Philadelphia, ages 4-14" (p. 201) while they played on their city block. The Goodwins claim that "arguing provides children with a rich arena for the development of proficiency of language, syntax, and social organization" (p. 200).

Goodwin and Goodwin focus on two types of grammatical markings, oppositional talk and format tying, which is a move to tie a turn of talk to the previous turn. The Goodwins note that in oppositional talk, the move is not simply made to call into question the previous turn's content (e.g., "An that happened *last* year. That happened *this* year" – p. 211, emphasis in original). The move is also made to call into question the "competence or status of the party who produced" (p. 209) the previous talk. With respect to format tying, children "tie not only to the type of action produced by the last speaker but also to the particulars of the wording" (p. 216) and in that way, the original speaker's words are literally used against him/her. An example is, "Don't gimme that. I'm not talking ta y:ou. I'm talking ta y:ou!" (p. 219). The Goodwins claim that oppositional talk and format tying are argumentative moves aimed at negotiating status within peer groups and serve to help children play with and learn linguistic structures.

The Goodwins note that children's argumentation is often times playful in nature and done with humor (a point Corsaro also makes), which is contradictory to the frequent portrayal of everyday argumentation as fighting. They also emphasize that girls and boys argue similarly, dispelling notions that argumentation is a male dominated practice (Goodwin & Goodwin, 1987; Goodwin, 2006). Lastly, the Goodwins call attention to the fact that many types of discourses are embedded in argumentation, such as "stories, request, commands, insults, explanations, excuses, threats, and warnings" (Goodwin & Goodwin, 1987, p. 239).

In their work on storytelling at family dinners, Ochs and colleagues (1992a, 1992b) make the case that storytelling socializes children into scientific practices, most notably theory construction. Because the Goodwins claim that stories are one type of discourse embedded in argumentation, we concentrate here on the pieces of Ochs and colleagues' work that relates to argumentative practices. The authors utilize Laudan's (1984) categorization of arguments in science as challenges "at a factual level, at the level of methodology, and/or at the level of ideology" (Ochs, Taylor, Rudolph, and Smith, 1992a, p. 54), where the majority of challenges in science are to factual claims. Ochs and colleagues find that around the dinner table, the majority of challenges are to methodological claims, such as a child's claims about how she handled a conflict situation at school.

As stories are drafted around dinner tables, they are then re-drafted through challenges to the original constructions. Ochs and colleagues see similarities between this and science where theories are drafted and then redrafted due to challenges to initial versions. They claim that these two practices are not as different as canonical images suggest.

> It may appear that scholarly narratives are challenged and redrafted on the basis of careful observation or logical reasoning, whereas everyday narratives of personal experience are not. The examples of family storytelling we have presented, however, indicate to us that observation…and logic…play an important role in challenges to initial versions. In this sense, the dialogic reworking of scholarly and everyday theories have common properties. (1992a, p. 66).

Lastly, Ochs and colleagues claim that familiarity, both with one's interlocutors and with the subject of what is being debated, affects argumentation practices. Familiarity breeds complex linguistic and cognitive processes. In other words, "environments conducive to collaborative explaining and critiquing are those marked by *familiarity*" (1992b, p. 43).

The concept of familiarity also appears in the work of Sarangapani (2003)—an ethnography of learning in an Indian village. She does not explore argumentation per se but does discuss what students in an Indian village school will accept as evidence, from whom they will accept it, and why the ask for it in the first place. Sarangapani uses Dewey's (1910/1997) concept of "primitive credulity" (p. 20), which explains that in everyday life, if one trusts a speaker or other source(s) of knowledge, then one will believe the claims espoused by that source of knowledge, even given slight evidence. The children in her study would only demand evidence from those they did not trust. If children felt that they needed to challenge a friend, they would challenge the friend using humor (note humor as a common thread) so that the friend was in no danger of being perceived as a liar. However, children claim that peers who are considered enemies are likely liars and therefore, their assertions cannot be believed and must be challenged.

Sarangapani highlights sources that according to children possess epistemic authority. These sources include people, such as parents, teachers, and older peers (people who have more schooling than the children and their peers), books, and television. Any knowledge presented by these sources is considered believable by the children and rarely, if ever, questioned. Children use these sources as evidence for their claims, if called on to justify those claims. Furthermore, when verifying claims, children turn to these sources and either ask the people listed above who are thought to possess expertise in the domain in which the claim is situated or consult books and/or television. Children also appeal to personal experience. "The feeling of certainty that accompanies what one has seen 'with one's own eyes' often makes the usual epistemic requirements of evidence and skepticism irrelevant" (p. 201).

The Indian children in the school Sarangapani studied engage in several practices in order to convince others that their knowledge claims are truthful and believable. For example, children try to establish personal expertise in whatever domain their claims are situated. In this practice, instead of offering evidence for their claims, children continue to offer additional domain-specific information they possess. Another practice is to speak claims in a rhyming format, which traditionally has conferred belief (note the possible similarities between this and the Italian preschool children's use of the cantilena in Corsaro's study).

Theoretical images of argumentation from cognitive psychology.

We now turn to scholars who, from a cognitive perspective, make the connection between argumentation and learning and thinking. Fahenstock (1999) documents that the connection between argumentation and learning is an ancient one. Aristotle frequently mentioned learning, defined as "imparting knowledge as the result of effective presentation of ideas and arguments, [and] in turn the result of making the best possible verbal choices (Kennedy, 1991, 242, 244, 245, 250, 252)" (p. 27).

Kuhn has written extensively on argumentation as a thinking practice. In her articles *Thinking as Argument* (1992) and *Connecting Scientific and Informal Reasoning* (1993), Kuhn claims that we have little understanding of why people hold the views they do about a variety of subjects, issues, and events. Her question is, "To what extent does a process of rational argument underlie the beliefs people hold and the opinions they espouse?" (1992, p. 156). Kuhn believes that we can use argument as a window through which to look not only at what people think but also how and why they think what they do. For Kuhn, argumentation is a cognitive process because one has to be aware of one's theories, which will lead to the ability to reflect on them and evaluate them using evidence. She claims that one has to be aware of evidence as qualitatively different from theory and one needs to be able to construct relationships between theory and evidence in order to either prove or disprove the theories in question. (1993).

Kuhn makes a distinction between two different types of argument; rhetorical and dialogic. She points to the American Heritage Dictionary (Morris, 1981) for the definition of rhetorical arguments – "a course of reasoning aimed at demonstrating the truth or falsehood of something" (1992, p. 157). She defines a dialogic argument "as a dialogue between two people who hold opposing views" (1992, p. 157). She claims that the two types of arguments involve the same cognitive acts of claim making, marshalling evidence to support claims, and evaluating evidence to judge the validity of claims. However for Kuhn, the rhetorical argument might seem less complex because it is not readily apparent in all cases what the opposing viewpoints relative to the argument are. She claims that every rhetorical argument contains a full dialogic argument and she designs a study to attempt to get people to articulate the full dialogic arguments contained in their rhetorical arguments.

Kuhn asked people in her study for their views on three topics: "1) What causes prisoners to return to crime after they are released? 2) What causes children to fail in school? 3) What causes unemployment?" (1992, p. 157). After they offered their opinions, she probed their reasoning by asking them to present evidence for their opinions. She also asked them to articulate viewpoints other than their own and asked them to present evidence to support those other viewpoints. She found that (a) most people in her study (her sample consisted of 160 people ranging in age from teenagers to people in their sixties) are certain that their beliefs are correct relative to these topics, (b) over half of them did not present what Kuhn refers to as "genuine evidence," which is evidence that "is differentiated from theory…and bears on the theory's correctness" (1992, p. 159), and (c) roughly sixty-percent of them could articulate other viewpoints different from their own but many had great difficulty articulating counterarguments that people holding these other viewpoints could muster against the study participants' stated opinions.

Kuhn claims that she found no sex or age difference in the ability to employ skills necessary to engage in argumentation. However, she did find that one's educational attainment did make a difference, with higher educational attainment levels increasing one's ability to employ these skills. She also found that the topic in question made no difference. In other words, people performed in similar ways across topics, which she says is a critical finding "because it suggests that we have identified forms of thinking that transcend the particular content or contexts in which they are expressed" (1992, p. 171).

Kuhn espouses the belief that one's epistemological beliefs can be ascertained through one's argumentation. Kuhn creates three categories of epistemological beliefs based on her study participants' reasoning. She categorizes people in the first category as absolutist. They view knowledge as certain and accumulative in nature. Kuhn states that about 50% of her participants held this epistemological belief. She categorizes about 35% of her participants as multiplists, her next category, because they see all knowledge as relative, "dictated only by personal tastes and wishes of the knower" (p. 169). Finally, there are those who are evaluative because they believe that knowledge is constructed based on evaluation and critique. Kuhn found that roughly 15% of her participants held this epistemological belief. Kuhn claims that it is only by holding an evaluative epistemology that people will see the value of argumentation. Kuhn links an evaluative epistemological worldview with scientific thinking. She states that scientists work "…to investigate a domain in which multiple variables interact and to draw conclusions about the causal relations that exist there" (p. 92).

However, Koslowski (1996) argues that "one's view of scientific inquiry determines one's assessment of scientific reasoning" (p. 251). She claims that many studies, such as Kuhn's, are designed based on the logical positivists' image of scientific inquiry. This view is one of scientific inquiry as rigid algorithm applicable to any scientific study regardless of the theoretical underpinnings. Koslowski argues that psychological studies of everyday reasoning that adopt this image of inquiry ask participants to engage with tasks that are "theoretically impoverished" (p. 251) and she claims this is because those psychologists believe that "one need not know anything about a subject area in order to engage in sound scientific reasoning about the area" (p. 277).

Koslowski also claims that another problem with studies based on a logical positivistic image of scientific inquiry assume that covariation is the gold standard of scientific thought instead of covariation being one piece of scientific thought along with theoretical and/or mechanistic considerations (which often times are used to determine which covariations are plausible). Koslowski's argument is that if study tasks are designed in the image of covariation, it is not surprising that results report that study participants cannot think scientifically because participants might be bringing theoretical and/or mechanistic considerations to bear on the tasks.

Koslowski argues for an image of scientific inquiry as "rules of thumb" (p. 264) and for an image of scientific reasoning as one of "bootstrapping," which she defines as "using theory to constrain data and using data in turn to constrain, refine, and elaborate theory" (p. 281). Given this view of scientific inquiry (versus a rigid algorithmic view) separating the processes of reasoning from what one is reasoning about is impossible. We again see that context is extremely important when engaging in argumentation in any domain.

Andriessen (2006) cites Kuhn's work as evidence that most people do not know how to argue and/or do not engage in the practice effectively. In order to remedy this situation, he proposes the notion of collaborative argumentation, which he says is the type of argumentation in which scientists engage. He claims that "argumentation in science is not oppositional and aggressive; it is a form of collaborative discussion in which both parties are working together to resolve an issue, and in which both scientists expect to find agreement by the end of the argument" (p. 443). Andriessen claims that if students are taught collaborative argumentation practices, then they will be arguing to learn. As part of participation in argumentation, students will be engaged in practices, such as elaboration, reflection, and reasoning, which Andriessen, citing Bransford, Brown, and Cocking (2001), claims are rich learning practices.

Learning scientists have detailed how argumentation supports specific learning mechanisms. Argumentation makes people's ideas visible, it can promote conceptual change because some of the ideas it surfaces might afford avenues for cognitive dissonance, it fosters co-construction of knowledge, and it provides space for deep articulation of the issues at hand (e.g., Andriessen, 2006; Bell, 1997, 2002, 2004). Andriessen warns that collaborative argumentation must be sans competition in order for learning to occur through a focus on "understanding, explanation and reasoning, and interpersonal success..." (p. 456). Design research has shown how social norms of collaborative debate can be cultivated in science classrooms (e.g., Bell and Linn, 2002).

Billig's (1987/1996) project is to bring the rhetorical tradition to bear on the cognitive theories of social psychology. He argues that through our arguments, our thoughts are revealed and he stresses that "…our thinking…may be based upon dialogue" (p. 142). Like Andriessen, Billig also champions a non-competitive image of argumentation in the tradition of Socrates. He feels that it is through dialogue that ideas are explored and generated. In this way, argumentation serves as a defense against orthodoxy, which Billig states is one of the implicit messages of his text (p. 22).

Like other scholars we have profiled, Billig discusses the importance of taking account of the context in which argumentation is occurring. He draws on Perelman (1979), who claims that issues of criticism and justification are central to argumentation. Perelman notes that both processes occur in social contexts and therefore, are "always 'situated' (p. 33)" (p. 117). Argumentation is understood only by examining both criticisms and justifications. In other words, "one cannot properly understand an argument, if one fails to grasp what it is arguing against" (p. 121) and because both criticisms and justifications are situated, one has to understand the larger social milieu in which the argumentation is embedded. He suggests that instead of asking what discourse is about, one should ask what it is opposing. If that question cannot be answered, the discourse is not argumentative in nature.

Implications for science education.

Turning for the last time to our heuristic represented in Figure 1, we have noted lines of research in science education that utilize some of the theoretical images of argumentation from the learning sciences. Again, we feel more should be done. For the most part, the fields of science education and the learning sciences do not often speak to each other in systematic ways for the purpose of bettering young people's science learning experiences. We argue that bridges should be built between these two communities and one way to do that is by creating research designs that take into account both science education and learning sciences theories. As science educators, when designing experiences for students that involve scientific practices, such as argumentation, explanation, and modeling, for example, we should study not only the purchase of our designs relative to students' images of science but we should also study whether, and if so how, these scientific practices are also learning practices. In other words, scholars in science education should pursue studies that test the hypothesis that science education interventions that incorporate various scientific practices lead to effective learning of science concepts and learning about the role of these practices in the scientific enterprise. We also believe scholars in the learning sciences have much to benefit from the theoretical perspectives and instructional approaches refined within science education. Given the discipline-specific trend within recent learning theory, we should work to synthesize theoretical perspectives across these two fields.

Readers will notice that we have highlighted "everyday argumentation" as a line of research that has not been given attention in the science education community. This line of research stems from the theoretical images of argumentation highlighted through ethnographic research. Some might be skeptical about the similarities between everyday and scientific argumentation. However, by looking at anthropological studies of science laboratories, we see that argumentation in these two spaces might be more similar than we might think. For example, Kyratzis (2004) reports that gossip talk is a type of argumentation prevalent in young people's peer groups. It functions to unify the views of the group. Knorr Cetina (1999) reports that in the laboratory "gossip is a kind of mangle through which all significant events and entities within an experiment and in its relevant surroundings are put. Technical gossip mixes report, commentary, and assessment regarding technical objects and regarding the relevant behavior of persons" (p. 203). The same type of talk appears to be functioning in similar ways in both settings. Another example pertains to Sarangapani's (2003) studies of young people's evidence and evidential (e.g., Aikhenvald, 2004) use. Clearly, the use of evidence and the citing of one's sources for that evidence are critical practices in science but they also appear to be common in everyday talk as well (e.g., Bricker and Bell, 2007). Attending to the specific features (e.g., linguistic, gesture) of young people's argumentative talk and action (e.g., Goodwin and Goodwin, 1987) might also serve as a way to build bridges between literacy and science, which many deem important to science learning and teaching (e.g., Saul, 2004). For those of us interested in designing interventions that engage students with what it means to argue scientifically, how can we capitalize on everyday talk and practices related to argumentation?

In response to that question and as a first step, we argue that much more needs to be understood about what argumentative competencies and understandings people bring with them to formal instructional moments that are designed to engage them with what it means to argue scientifically. To that end, we now detail our research, which is examining young people's argumentation across the settings they frequent and as part of their activity systems within those settings (cf. Goffman, 1961).

Young People's Everyday Encounters with Argumentation

Our own research on young people's everyday argumentation is part of a team ethnography of thirteen young people's encounters with science and technology across the everyday settings of their lives (e.g., home, school, neighborhood, museums) (see Bell, Bricker, Lee, Reeve & Zimmerman, 2006 for a more detailed account of our research). We began collecting data two and a half years ago when our focal participants were in the fourth and fifth grade at a local elementary school with which we have a partnership. Roughly one hundred and twenty people are consented into the study including our thirteen focal participants, many of their family members and peers, and their teachers. The sample is ethnically, linguistically, and socioeconomically diverse. Many of our families are first generation immigrants to the United States. To date, we have approximately eighteen hundred hours of video and audio data, as well as fieldnotes, digital photographs, documents, and other artifacts. We utilize ethnographic observation, participant observation, and interview methods, as well as clinical interviews and self-documentation tasks, where we give participants digital cameras and ask them to document images of argument, for example, in their lives.

Our research focuses on four conceptual themes related to children's current and future science and technology learning: (a) personally relevant biology topics, specifically personal health, nutrition, and the local environment; (b) argumentation, both in everyday and formal reasoning contexts; (c) images of science to which children are exposed (e.g., through school, the media, social encounters), as well as how such images affect children's definitions of science and their construction of academic identities; and (d) use of digital technologies, especially cellular phones, videogames, and the Internet.

With respect to our argumentation research, we explore young people's everyday argumentation from structural, linguistic, cultural, and intentionality lenses. With respect to analysis, we employ both etic and emic perspectives. We borrow these concepts from linguistics and anthropology. Given any action or event, an etic perspective is the observer's accounting and interpretation of the action or event, whereas an emic perspective is the member's or participant's accounting and interpretation of the action or event (Harris, 1987; Pike, 1954). We take our etic accounts of argumentation from the various theoretical images explicated in this article. Our emic accounts of argumentation come from our research participants. One finding that might have particular relevance to the design of science education learning environments is the meaning young people associate with the word "argument." Possibly not surprising, many associate practices of social dispute—such as yelling and fighting—with the term. If we are asking science students to "argue" scientifically, what impact do their meanings attached to the word "argument" have for successful engagement with that endeavor? This might also be related to the point about familiarity that Ochs and her colleagues (1992b) highlight. What types of classroom climates might we have to foster in order for students to feel that they can successfully engage with practices, such as argumentation, in the first place? In various analyses we currently have underway, we document the features of children's everyday argumentation and its relevancies to science education.

Summary Comments

There are many goals and purposes for science education. The field has reached a point of consensus that scientific practices, such as argumentation, should not only be used to help young people learn scientific theories and concepts but to also ensure that they learn how to engage in scientific discourse, learn about the workings of the scientific enterprise, and come to apply scientific concepts and practices to everyday decisionmaking (e.g., American Association for the Advancement of Science, 1989, 1993; Duschl, Schweingruber, and Shouse, 2007; National Research Council, 1996; Osborne, Collins, Ratcliffe, Millar, and Duschl, 2003). In order to gain insight into how scientific theories come into existence and what practices and processes are involved in theory construction endeavors, young people should be engaged in science classrooms with questions such as *who* develops scientific theories, *how*, *where*, *when*, *why*, and of course, young people should be provided with ample reasons for why they should care about the epistemic work of science. Making the workings of the scientific enterprise visible to young people should help them better understand scientific theories and how they were formulated through human activity. However, it may have other, more profound effects, such as granting all young people access to the culture and products of science.

We have used the scientific practice of argumentation as a model for our argument that the field of science education's attempts to integrate images of scientific practice deeply into the work of science education have been hampered by a narrow theoretical consideration of the forms and purposes of those practices—and that many of the specific theoretical images like the kinds presented in the previous sections can be used to further inform important aspects of the endeavor. Relative to argumentation, that practice is not only about learning to coordinate evidence with claims and being causal in one's theorizing. It is also about developing shared understanding of complex concepts, persuading others about science-related disputes, making personal decisions that are consequential, and navigating the accountability structures of formal schooling. To this end, we believe that it is necessary to leverage a broader theoretical set of argumentative images than has been used to date for understanding what argumentative forms and purposes are associated with the fields of science as well as what everyday argumentative competencies youth develop and bring to the classroom. If we are successful in this more comprehensive pursuit of the relevant images of argumentation and other epistemic practices (e.g., modeling, explanation) then we will likely be better positioned to make progress on the range of goals associated with science education.

References

Aikhenvald, A.Y. (2004). *Evidentiality*. Oxford, UK: Oxford University Press.

American Association for the Advancement of Science (1989). *Science for all Americans*. New York, NY: Oxford University Press.

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

Andrews, R. (2005). Models of argumentation in educational discourse. *Text, 25*(1), 107-127.

Aristotle, & Kennedy, G.A. (1991). *Aristotle on rhetoric: A theory of civic discourse.* New York, NY: Oxford University Press.

Bell, P. (1997). Using argument representations to make thinking visible for individuals and groups. In R. Hall, N. Miyake & N. Enyedy (Eds.), *Proceedings of CSCL '97: The Second International Conference on Computer Support for Collaborative Learning* (pp. 10–19). Toronto, Canada.

Bell, P. (2002). Using argument map representations to make thinking visible for individuals and groups. In T. Koschmann, R. Hall & N. Miyake (Eds.), *CSCL 2: Carrying Forward the Conversation* (pp. 449-485). Mahwah, NJ: Lawrence Erlbaum Associates.

Bell, P. (2004). Promoting students' argument construction and collaborative debate in the science classroom. In M. C. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 115-143). Mahwah, NJ: Erlbaum.

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

Bell, P., & Linn, M. C. (2002). Beliefs about science: How does science instruction contribute?

In B. K. Hofer & P. R. Pintrich (Eds.), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing* (pp. 321-346). Mahwah, NJ: Lawrence Erlbaum.

Bell, P., Bricker, L. A., Lee, T. R., Reeve, S., & Zimmerman, H. T. (2006). Understanding the cultural foundations of children's biological knowledge: Insights from everyday cognition research. In S. A. Barab, K. E. Hay & D. Hickey (Eds.), *Proceedings of the Seventh International Conference of the Learning Sciences (ICLS)* (pp. 1029-1035). Mahwah, NJ: LEA.

Barnes, B, Bloor, D., & Henry, J. (1996). *Scientific knowledge: A sociological analysis.* Chicago, IL: The University of Chicago Press.

Bazerman, C. (1988). *Shaping written knowledge*. Madison: University of Wisconsin.

Billig, M. (1987/1996). *Arguing and thinking: A rhetorical approach to social psychology* (new ed.). Cambridge, UK: Cambridge University Press.

Blackburn, S. (1994). *The Oxford dictionary of philosophy*. Oxford, UK: Oxford University Press.

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

Brante, T. (1993). Reasons for studying scientific and science-based controversies. In T. Brante, S. Fuller & W. Lynch (Eds.), *Controversial science : From content to contention*. Albany, NY: State University of New York Press.

Bricker, L.A., & Bell, P. (2007, October). *Evidentiality and evidence use in children’s talk across everyday contexts*. Paper presented at the annual meeting of the Society for Social Studies of Science (4S), Montreal, Canada.

Ceccarelli, L. (2001). *Shaping science with rhetoric: The cases of Dobzhansky, Schrödinger, and Wilson*. Chicago, IL: The University of Chicago Press.

Collins, H. M., & Pinch, T. (1993). *The Golem: What Everyone Should Know About Science*. New York: Cambridge University Press.

Corsaro, W.A. (2003). *We're friends right? Inside kids' culture.* Washington, DC: Joseph Henry Press.

Dewey, J. (1910/1997). *How we think*. Mineola, NY: Dover Publications, Inc.

Duschl, R.A., & Grandy, R.E. (2004). Reconsidering the character and role of inquiry in school science: Framing the debates. Draft paper for the *Inquiry Conference on Developing a Consensus Research Agenda.* February 16-19, 2005.

Duschl, R.A., Schweingruber, H.A., & Shouse, A.W. (Eds). (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, DC: National Academy Press.

Erduran, S., & Jiménez-Aleixandre, M.P. (Eds). (2007). *Argumentation in science education: Perspectives from classroom-based research.* Dordrecht: Springer

Fahnestock, J. (1986). Accommodating science: The rhetorical life of scientific facts. *Written Communication, 3*(3), 275-296.

Fahnestock, J. (1999). *Rhetorical figures in science.* New York, NY: Oxford University Press.

Galison, P. (1997/1998 abridged). Trading zone: Coordinating action and belief. In M. Biagioli (Ed.), *The science studies reader* (pp. 137-160). New York, NY: Routledge.

Gieryn, T.F. (1992). The ballad of Pons and Fleischmann: Experiment and narrativity in the (un)making of cold fusion. In E. McMullin (Ed.), *The social dimensions of science* (pp. 217-243). Notre Dame, IN: University of Notre Dame Press.

Goffman, E. (1961). *Encounters: Two studies in the sociology of interaction.* Indianapolis, IN: The Bobbs-Merrill Company, Inc.

Goodwin, M. H. (2006). *The hidden life of girls: Games of stance, status, and exclusion*. Malden, MA: Blackwell.

Goodwin, M.H., & Goodwin, C. (1987). Children's arguing. In S.U. Philips, S. Steele, and C. Tanz (Eds.), *Language, gender, and sex in comparative perspective* (pp. 200-248). Cambridge, UK: Cambridge University Press.

Groarke, L. (1997). Logic, art and argument. *Informal Logic, 18*(2&3), 105-129.

Harris, M. (1987). *Cultural anthropology* (2^{nd} Ed.). New York, NY: Harper & Row Publishers.

Kelly, G.J., & Bazerman, C. (2003). How students argue scientific claims: A rhetorical-semantic analysis. *Applied Linguistics, 24*(1), 28-55.

Knorr Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge, MA: Harvard University Press.

Koslowski, B. (1996). *Theory and evidence: The development of scientific reasoning*. Cambridge, MA: The MIT Press.

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review, 62*(2), 155-178.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319-337.

Kuhn, L., Kenyon, L., & Reiser, B. J. (2006). Fostering scientific argumentation by creating a need for students to attend to each other's claims and evidence. In S. A. Barab, K. E. Hay & D. Hickey (Eds.), *Proceedings of the Seventh International Conference of the Learning Sciences (ICLS)* (pp. 370 - 375). Mahwah, NJ: LEA.

Kuhn, T.S. (1962). *The structure of scientific revolutions* (3rd ed.). Chicago, IL: University of Chicago Press.

Kukla, A. (1998). *Studies in scientific realism*. Oxford, UK: Oxford University Press.

Kyratzis, A. (2004). Talk and interaction among children and the co-construction of peer groups and peer culture. *Annual Review of Anthropology, 33*, 625-649.

Latour, B., & Woolgar, S. (1979/1986). *Laboratory life: the construction of scientific facts*. Princeton, NJ: Princeton University Press.

Laudan, L. (1984). *Science and values: The aims of science and their role in scientific debate.* Berkeley, CA: University of California Press.

Lemke, J.L. (1990). *Talking science: Language, learning, and values*. Westport, CT: Ablex Publishing.

Lemke, J.L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J.R. Martin and R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 87-113). New York, NY: Routledge.

Longino, H.E. (1990). *Science as social knowledge: Values and objectivity in scientific inquiry.* Princeton, NJ: Princeton University Press.

Morris, W. (Ed.). (1982). *American Heritage Dictionary*. Boston, MA: Houghton Mifflin.

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

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education, 21*(5), 553-576.

Norris, S.P., & Phillips, L.M. (2004). Reading as inquiry. Draft paper for the *Inquiry Conference on Developing a Consensus Research Agenda.* February 16-19, 2005.

Ochs, E., Taylor, C., Rudolph, D., & Smith, R. (1992a). Storytelling as a theory-building activity. *Discourse Processes, 15*, 37-72.

Ochs, E., & Taylor, C. (1992b). Science at dinner. In C. Kramsch & S. McConnell (Eds.), *Text and context: Cross-disciplinary perspectives on language study* (pp. 29-45). Lexington, MA: DCHeath.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40(7)*, 692-720.

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

Pera, M. (1994). *The discourses of science* (C. Botsford, Trans.). Chicago, IL: The University of Chicago Press.

Perelman, CH. (1979). *The new rhetoric and the humanities*. Dordrecht: D. Reidel.

Perelman, CH., & Olbrechts-Tyteca (1969). *The new rhetoric: A treatise on argumentation* (J. Wilkinson & P. Weaver, Trans.). South Bend, IN: University of Notre Dame Press.

Pike, K.L. (1954). *Language in relation to a unified theory of the structure of human behavior.* Ann Arbor, MI: Braun-Brumfield, Inc.

Prelli, L.J. (1989). *A rhetoric of science: Inventing scientific discourse*. Columbia, SC: University of South Carolina Press.

Prior, P. (2005). Toward the ethnography of argumentation: A response to Richard Andrews' 'models of argumentation in educational discourse.' *Text, 25*(1), 129-144.

Roth, W.-M., & Barton, A.C. (2004). *Rethinking scientific literacy*. New York, NY:Routledge.

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

Sarangapani, P.M. (2003). *Constructing school knowledge: An ethnography of learning in an Indian village.* New Delhi, India: Sage Publications.

Saul, E.W. (Ed.). (2004). *Crossing borders in literacy and science instruction: Perspectives on theory and practice*. Arlington, VA: NSTA Press.

Schwab, J. (1962). The teaching of science as enquiry, *The teaching of science* (pp. 3-103). Cambridge, MA: Harvard University Press.

Simosi, M. (2003). Using Toulmin's framework for the analysis of everyday argumentation: Some methodological considerations. *Argumentation, 17*, 185-202.

Sismondo, S. (2004). *An introduction to science and technology studies*. Malden, MA: Blackwell Publishing.

Slade, C. (2003). Seeing reasons: Visual argumentation in advertisements. *Argumentation, 17*, 145-160.

Stanford, P.K. (2006). Instrumentalism. In S. Sarkar, and J. Pfeifer (Eds), *The philosophy of science: An encyclopedia* (pp. 400-405). New York, NY: Routledge, Inc.

Toulmin, S.E. (1958/2003). *The uses of argument* (updated ed.). Cambridge, UK: Cambridge University Press.

Toulmin, S.E. (1976). *Knowing and acting: An invitation to philosophy*. New York, NY: Macmillan.

Toulmin, S.E., Rieke, R., & Janik, A. (1984). *An introduction to reasoning* (2nd ed.). New York, NY: Macmillan Publishing Company, Inc.

van Eemeren, F.H., Grootendorst, R., & Snoeck Henkemans, A.F. (2002). *Argumentation: Analysis, evaluation, presentation*. Mahwah, NJ: Lawrence Erlbaum Associates.

van Eemeren, F.H., & Grootendorst, R. (2004). *A systematic theory of argumentation: The pragma-dialectic approach*. Cambridge, UK: Cambridge University Press.

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, John-Steiner, Scribner, S., & Souberman, E., Eds.). Cambridge, MA: Harvard University Press.

Watson, J.D., & Crick, F.H.C. (1953). Molecular structure of nucleic acids. *Nature, 171*(4356), 737-738.

Figure 1: Contributing theoretical images of argumentation to the science education enterprise